WATER

AND

PUBLIC HEALTH.

THE RELATIVE PURITY OF WATERS FROM DIFFERENT SOURCES.

BY

JAMES H. FUERTES,

Member of the American Society of Civil Engineers.

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PREFACE.

THE idea suggested itself to the writer some time past to group the principal cities of the world into classes according to the quality of their public water-supplies and then to make a comparative study of their mortality statistics. In the matter which follows, which is the outgrowth of this suggestion, considerable ground has been gone over briefly which has already been fully covered, but it seemed advisable to bring some of these widely scattered observations together in order to preserve continuity in the development of the subject and to permit, by statistical evidence, the exclusion of the minor influences, in order that the importance of pure water might stand out in bolder relief.

The statistics which have been collected introduce certain elements of inexactness and uncertainty, which, it is true, may be urged against all such studies. The principal elements of uncertainty enter in the calculation of the death-rate, as the population assumed may be incorrect, or, there may be errors in the reports of the physicians or health boards. It may be assumed,

however, that in all large cities these causes of error are perhaps equal, and that by compiling the statistics of a great number the inaccuracies will counterbalance so as not to seriously influence the general deductions that may be drawn.

The statistics of typhoid fever and population in our American cities are taken mostly from the published reports of the cities and of the State boards of health. Those which could not be obtained from these sources have been secured by correspondence. The similar data for the European cities were obtained in the same manner; much of this information has already been compiled and published, however, in a very interesting paper on "The Water-supplies of Cities," by J. W. Hill, M. Am. Soc. C. E., read in January, 1896, before the faculty and students of the University of Illinois. The statistics of a few of the cities have been taken from this compilation.

The descriptions of the sources of supply for the American cities are from private notes, municipal reports, reports on improved supplies, and descriptions in current literature. Many supplies, where particular features demanded study to facilitate a proper classification, have been the subject-matter of much correspondence. The sources of supply of the European cities are described mainly from my private notes, supplementing those which I lacked by reference to published reports and descriptions.

I gladly take this opportunity to acknowledge my great appreciation of the kindness of the many engineers, government and municipal officers, water-works

officials, health officers, and physicians, both at home and abroad, who have, frequently at great individual trouble, favored me with the information desired; it would be impracticable to make individual acknowledgments to so great a number of persons. I wish, however, to make one exception in favor of my friend Rudolph Hering, C.E., who has extended to me many friendly professional courtesies.

JAMES H. FUERTES.

NEW YORK, *December*, 1896.

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WATER AND PUBLIC HEALTH.

CHAPTER I.

ETIOLOGY AND PROPHYLAXIS OF TYPHOID FEVER.

I. General Considerations.

The bacilli of typhoid fever have rarely been found in a public drinking-water supply, although close watch to detect them has been kept for several years. Negative results in the search for the bacilli, however, would not prove that they are not frequently present, because, since they do not propagate to any considerable extent in fresh water, they become widely scattered by dispersion, and therefore are difficult to detect by analysis. The difficulties are further increased by the impossibility in laboratory experiments of examining more than a very small quantity of water at a time.

There is much evidence in support of the belief that typhoid fever in man results from the development of the B. typhosis in his body. The bacillus of Eberth has been repeatedly found in polluted waters suspected

of causing typhoid fever. Fraenkel * and Simmonds state that they have produced the disease in monkeys, rabbits and mice by inoculation with pure cultures of the microbe, and recently Sanarelli † has announced that he has also been successful in his labors in the same field.

The typhoid bacillus has frequently been found in the dejecta of typhoid patients in the early stages of the disease, and it has been found by *post-mortem* examinations in the organs of the bodies of persons dying of typhoid fever.

If it be granted that this is the cause of typhoid fever, the human body constitutes a laboratory which can analyze a greater quantity of water at a time than would be possible in experiments. Certain organs of the body, by their various temperatures and chemical compositions, afford favorable conditions for the growth of many specific microbes. If then a person should have typhoid fever after having drunk water that is known to have been recently polluted with the dejecta of another typhoid patient, we would not err in attributing his sickness to that cause. Under such assumptions we could not then desire a better bacterial analysis of a water known to be polluted with the dejecta of typhoid-fever patients than would be given by the health records of a city supplied with such water, where every inhabitant may be considered as a culture-plate ready for inoculation.

It is natural and rational to look to the water for a

* Die Aetiologische Bedeutung des Typhus-bacillus, 1886.

† See Annales de l'Institut Pasteur.

predominating cause of infection, because ultimately, unless deprived of life, bacilli from the dejecta of typhoid patients find their way by surface washings, percolation, or direct discharge through sewers and drains, into the ground-water or watercourses which contribute to our water-supplies. The cases where the weightiest circumstantial evidences have led to the charging of water-supplies with the responsibility for typhoid-fever epidemics are very numerous.

A recently reported case at Cuxhaven on the Elbe, Fig. 1, is quoted by Dr. J. J. Reincke of Hamburg, in a paper before the Hamburger Aerztlichen Verein, June 2, 1896, entitled "Zur Epidemiologie des Typhus in Hamburg und Altona." * In this paper he states that in 1894, of the 52 cases which occurred in the village, 22 were along a ditch that supplied water for many families, and that had undoubtedly been infected by a case of typhoid from a hospital near by.

In 1895 its greatest severity was centred principally about two limited localities. One of these was around an infected well in the water of which Professor Dunbar, on September 14th, isolated bacilli which "were not different from the typhoid bacilli." Eighty-one people reside around the court in which this well was situated, of whom 23 were taken sick with typhoid fever. Of 18 persons living in a court in another locality, where an open ash and refuse pit was used also as a dumping-place for night-soil, 12 were taken sick with typhoid; through the servants and members of the afflicted families it was carried to other localities.

* Deutsche Vierteljahresschrift für öffentliche Gesundheitspflege, vol. XXVIII., part 3, 1896.

CUXHAVEN, GERMANY

DEATHS FROM TYPHOID FEVER IN 1894, •
" " " " " 1895, ∘

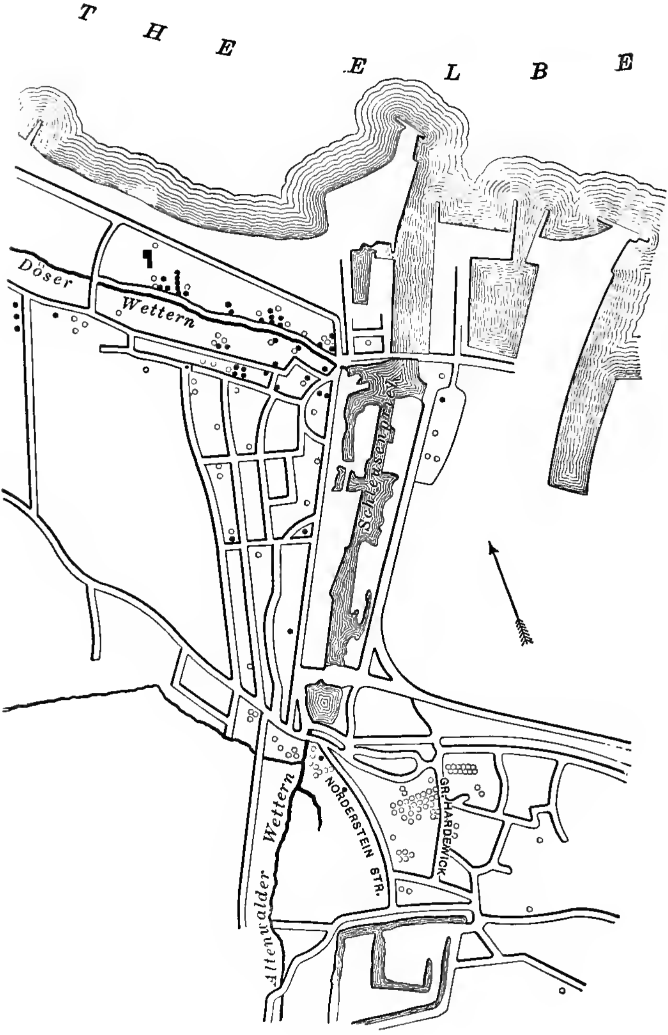


FIG. 1.

II. Rainfall and Typhoid Fever.

Before commencing a discussion of the data that have been collected it may be advisable to say a word about the different theories advanced to account for typhoid propagation. There are two generally proposed theories, the drinking-water theory and the ground-water theory, both of which have enthusiastic advocates. In support of their propositions there is an enormous accumulation of published statistical data, and it is not the purpose of this study to follow out the merits of either theory in a general way. There are of course other modes of infection by which typhoid fever can be introduced, but the reference here is to its origination and perpetuation in abnormal proportions.

In general, the bacillus can be conveyed into a water-supply in one of the following ways:

(*a*) By its carriage directly into a stream with the sewage of a city.

(*b*) By its being carried into a stream by surface washing from rain, snow, etc.

(*c*) By its being carried down into the subsoil by percolation.

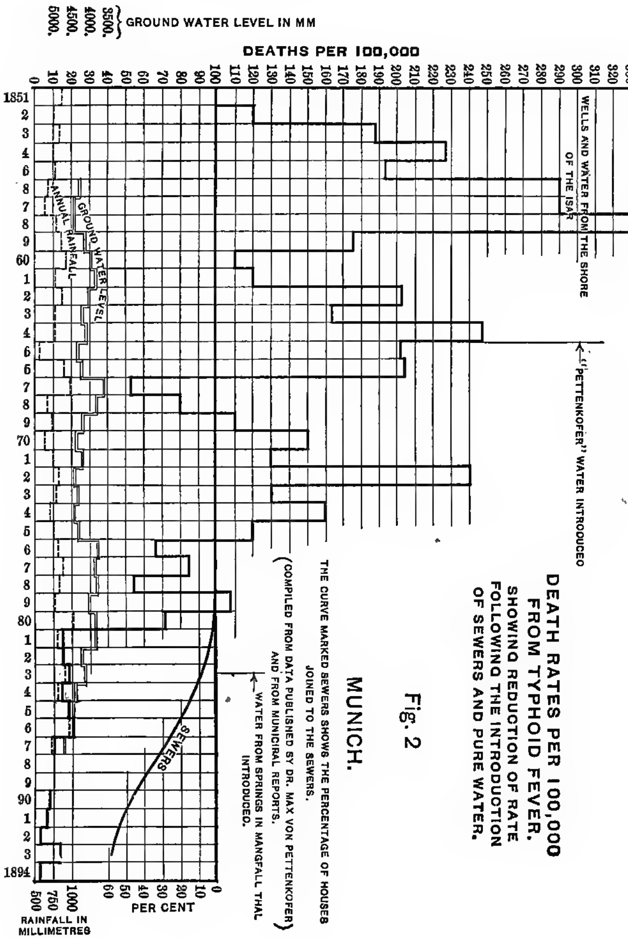
(*d*) By flying insects, birds, etc.

(*e*) By wind and rain.

In our large cities using well-waters I have been unable to show any well-defined relation between the precipitation of rainfall (fluctuation of ground-water level) and the cases of typhoid. The reason is, per-

haps, that the cities for which I have such records, Washington and Louisville, use also a large amount of other water subject to pollution, so that it is impossible to differentiate the effect of the rainfall. The statistics of Munich, which are given in Fig. 2, show this effect very consistently; it will be seen that when the ground-water level was low typhoid fever was high, and *vice versa*. The same is true also of Hamburg and Altona, Fig. 3. If the typhoid-fever death-rate is dependent alone upon the fluctuations of the ground-water level, we should expect that it would not be affected by the quality of the water supplied for drinking purposes, and that in cities provided with sewers and drains there would be uniformly lower and less fluctuating typhoid death-rates than in those not drained.

We find, however, cities like Washington, Philadelphia, Pittsburgh, and Cincinnati with very high and variable rates, while many others, having no better drainage systems, have very low rates with a small range of fluctuation. It has not been possible to get records of the ground-water levels at the different cities. This, however, must be a function of the rainfall and in a period of several years, it would be in some degree proportional to and vary in the same direction with it. A curve plotted with the annual precipitation for ordinates, and the years for abscissæ, should be similar in shape then to one representing the ground-water fluctuations year by year for the same period, providing the ground-water level was not maintained constant by deep drainage.



MUNICH.

Fig. 2

DEATH RATES PER 100,000 FROM TYPHOID FEVER. SHOWING REDUCTION OF RATE FOLLOWING THE INTRODUCTION OF SEWERS AND PURE WATER.

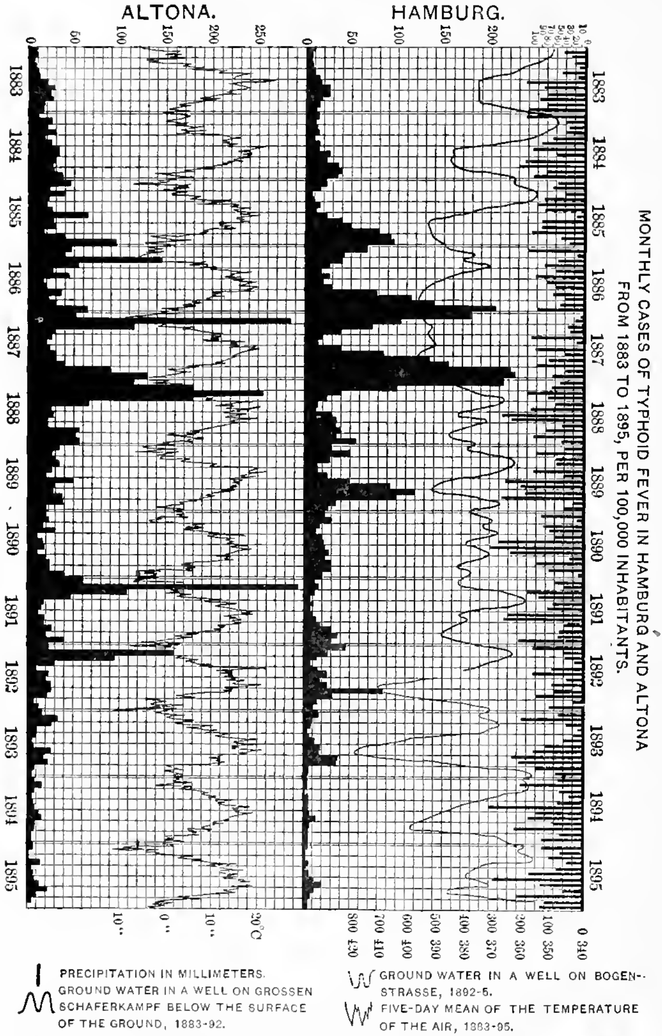


FIG. 3.—Dr. Reincke, in Paper before Hamburger Aerzt. Verein. June 2, 1896. Pub. in Vierteljahresschrift für öffentliche Gesundheitspflege, vol. 28, part 3, 1896.

Figs. 4 to 45 show the typhoid-fever death-rates and the annual precipitation for the years 1890–1895, inclusive, for many American cities. The data from which they are compiled will be found in Appendices A and C.

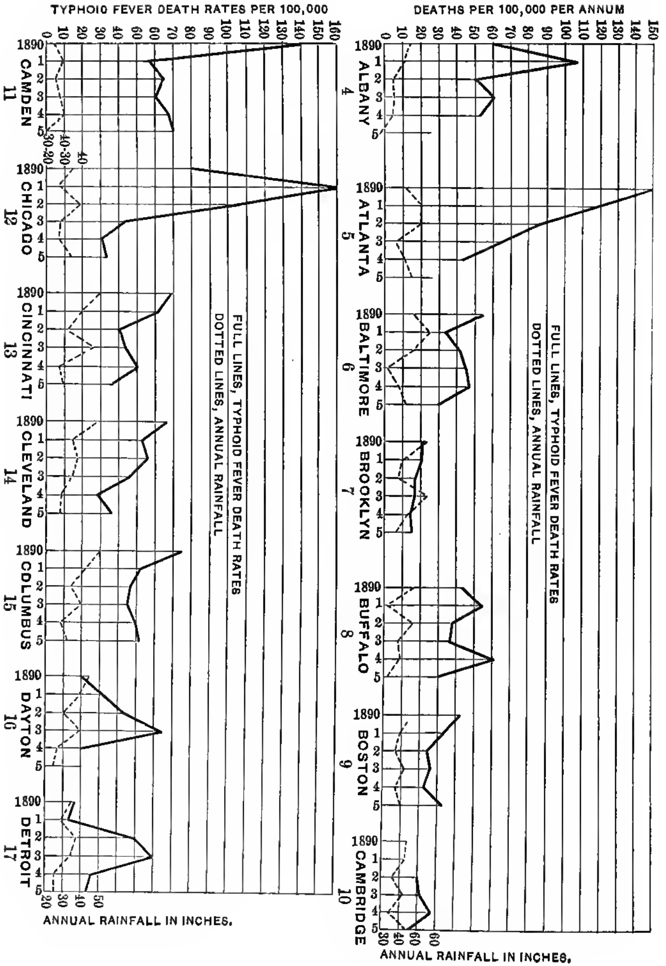
In Boston, Cleveland, Columbus, Detroit, Louisville, New York, Paterson, Pittsburgh, San Francisco, and Toledo there is a remarkable parallelism between the typhoid curves and the rainfall curves: in years of high rainfall typhoid was high, with but one or two exceptions. These cities represent many classes of water—supplies drawn from impounding reservoirs, lakes, small surface gathering-grounds, large normal rivers, and sewage-polluted rivers—and follow a law directly opposite to that followed by Munich, Hamburg and Altona.

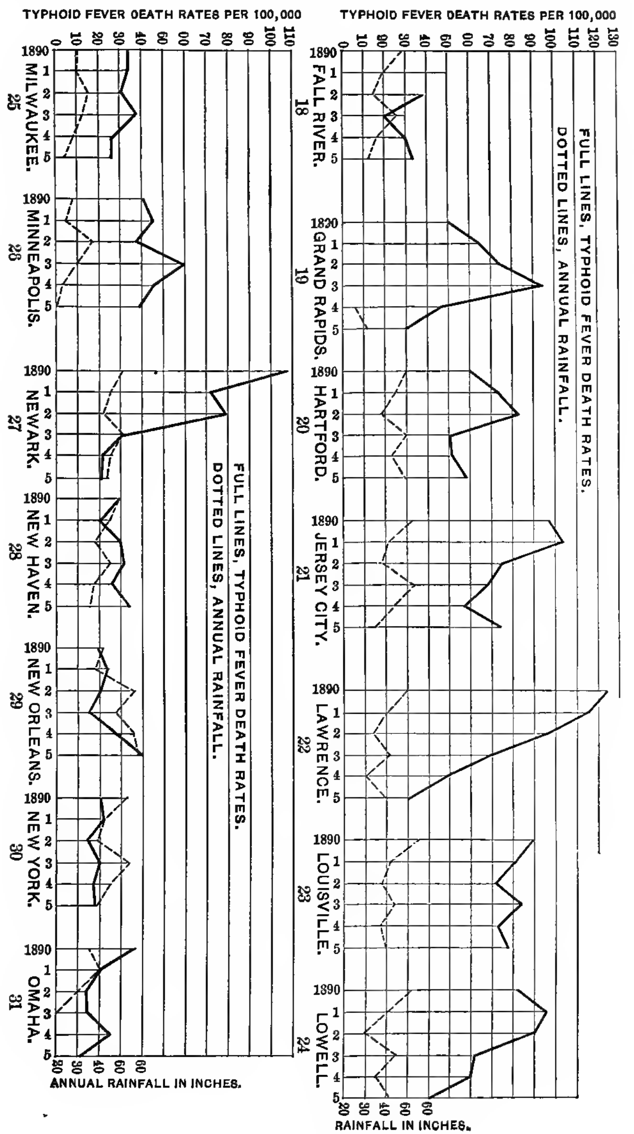
I will call attention to the fact that it is possible for all these supplies to be polluted by the washings from the surface,* or by percolation towards the water-supply sources; that is to say, the more rainfall the more polluting matter is washed into the source of supply.

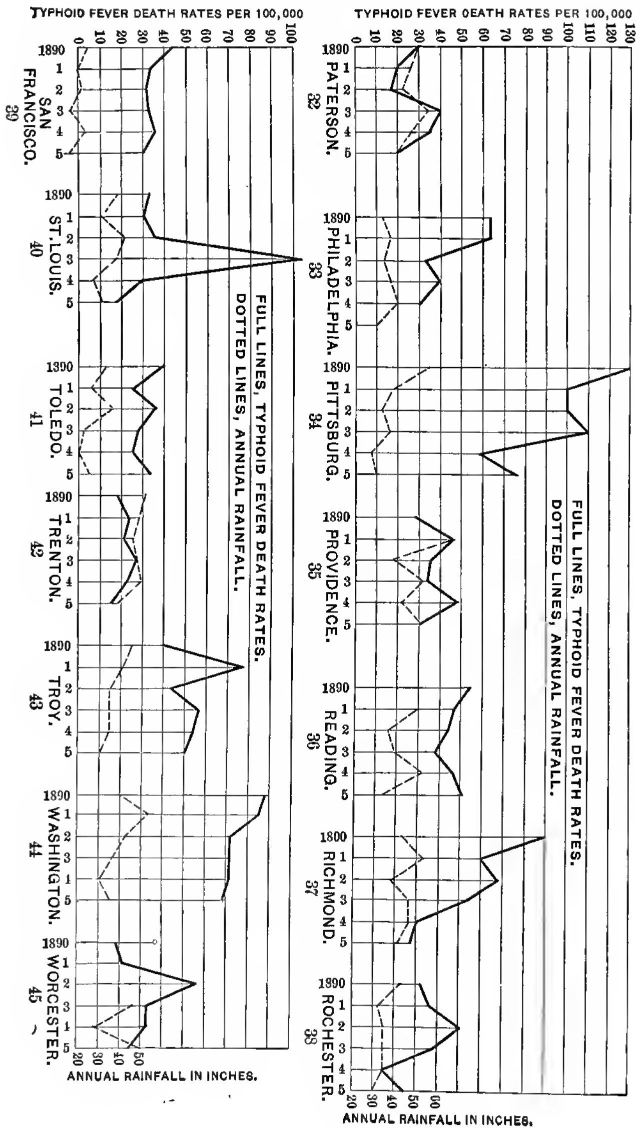
An interesting case of this occurred in the valley of the river Tees in England.† In the drainage area of

* An excellent paper on the bacteriology of river-waters, and treating of the fluctuation of the bacteria in river-waters with rainfall, is published in vol. VII., Memoirs of Nat. Acad. of Sciences, by Dr. John S. Billings, detailing the investigations of Dr. J. H. Wright, Scott Fellow in Hygiene, Univ. of Penn., 1892–3.

† Barry, Report on Enteric Fever in Tees Valley. Thirty-first Annual Report of Local Gov't Board, 1890–91. Report of Med. Officer for 1891. London, 1893.


TYPHOID FEVER DEATH RATES PER 100,000
CAMDEN 11
CHICAGO 12
CINCINNATI 13
CLEVELAND 14
COLUMBUS 15
DAYTON 16
DETROIT 17
FULL LINES, TYPHOID FEVER DEATH RATES
DOTTED LINES, ANNUAL RAINFALL
ANNUAL RAINFALL IN INCHES.
DEATHS PER 100,000 PER ANNUM
ALBANY 4
ATLANTA 5
BALTIMORE 6
BROOKLYN 7
BUFFALO 8
BOSTON 9
CAMBRIDGE 10
FULL LINES, TYPHOID FEVER DEATH RATES
DOTTED LINES, ANNUAL RAINFALL
ANNUAL RAINFALL IN INCHES.


TYPHOID FEVER DEATH RATES PER 100,000
MILWAUKEE. 25
MINNEAPOLIS. 26
NEWARK. 27
NEW HAVEN. 28
NEW ORLEANS. 29
NEW YORK. 30
OMAHA. 31
FULL LINES, TYPHOID FEVER DEATH RATES.
DOTTED LINES, ANNUAL RAINFALL.
ANNUAL RAINFALL IN INCHES.
TYPHOID FEVER DEATH RATES PER 100,000
FALL RIVER. 18
GRAND RAPIDS. 19
HARTFORD. 20
JERSEY CITY. 21
LAWRENCE. 22
LOUISVILLE. 23
LOWELL. 24
FULL LINES, TYPHOID FEVER DEATH RATES.
DOTTED LINES, ANNUAL RAINFALL.
RAINFALL IN INCHES.


TYPHOID FEVER DEATH RATES PER 100,000
SAN FRANCISCO. 39
ST. LOUIS. 40
TOLEDO. 41
TRENTON. 42
TROY. 43
WASHINGTON. 44
WORCESTER. 45
FULL LINES, TYPHOID FEVER DEATH RATES.
DOTTED LINES, ANNUAL RAINFALL.
ANNUAL RAINFALL IN INCHES.
TYPHOID FEVER DEATH RATES PER 100,000
PATERSON. 32
PHILADELPHIA. 33
PITTSBURG. 34
PROVIDENCE. 35
READING. 36
RICHMOND. 37
ROCHESTER. 38
FULL LINES, TYPHOID FEVER DEATH RATES.
DOTTED LINES, ANNUAL RAINFALL.
ANNUAL RAINFALL IN INCHES.

this river are numerous villages, some, with a total population of 219,435, drinking the water of the Tees, which is polluted with surface drainage and sewage; the rest, with a population of 284,181, have other supplies, not polluted. It is shown that in those cities using the Tees water the typhoid fluctuates synchronously with the rainfall, and in the rest, not using it, there is no connection or similarity between the rainfall and typhoid curves.

Dr. J. J. Reincke says on this point regarding the river Elbe at Hamburg: * "Whether the river-water carries typhoid bacilli in any considerable quantity in suspension from surface washings after rainfalls and the melting of snow is not positively known; nevertheless it is worthy of record that the Landrathsamt of Winsen, in a public proclamation issued in September last year warned the people against the use of the waters of the Ilmenau, because of the simultaneous existence of typhoid fever along the whole length of the river. In Lüneburg, which lies on this river, there was a very extended epidemic. This little river empties into the Elbe above Hamburg,† opposite the Zollenspieker."

Baltimore, Md., is the only large city in the United States of which I have records where the typhoid fever becomes consistently high with low annual rainfalls, similar to the conditions which formerly existed

* "Zur Epidemiologie des Typhus in Hamburg und Altona" (see note, page 3.)

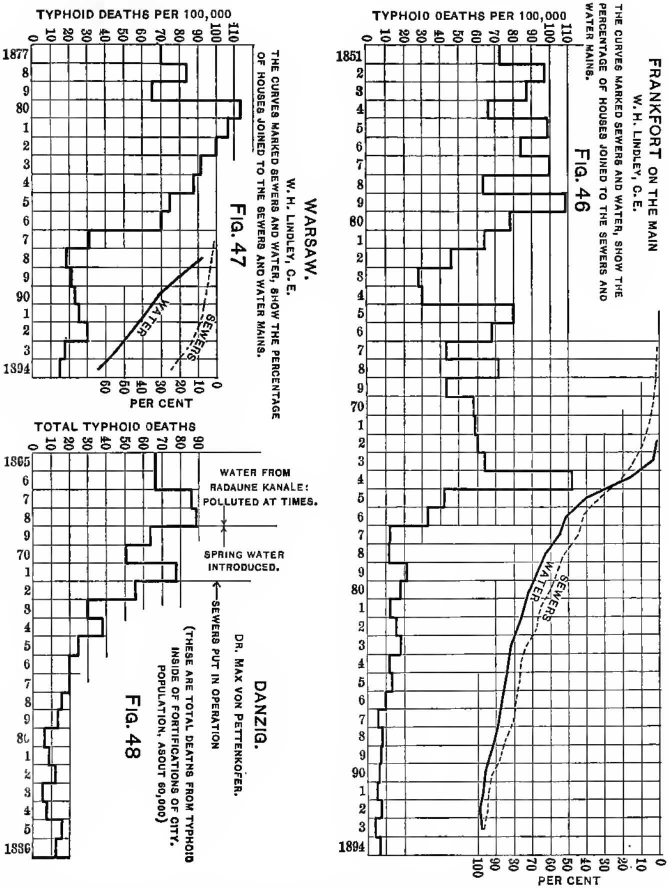
† About 10 miles above the intake of the Hamburg water-works. —J. H. F.

at Munich, Hamburg and Altona. Baltimore has as yet no sewerage, and the house-drainage is disposed of largely into cesspools and outhouses, giving conditions for a polluted subsoil. All the other cities shown on these charts, except New Orleans, have sewerage, and in them the typhoid-fever death-rate does not seem to show any correspondence with the rainfall rate, excepting at Baltimore and certain cities where the pollution may be occasioned by the surface washings into the reservoirs or streams furnishing the sources of supply. This state of affairs is not apt to be the case in smaller cities * not having sewers and depending upon wells for water. Among such it is very probable that a large proportion will follow the same law as Baltimore, although Baltimore uses no well-water.

III. Effect of Pure Water and Sewers upon Typhoid-fever Death-rates.

In order to show the correspondence between the decrease in death-rates from typhoid fever and the gradual introduction of sewers and pure water, I have plotted in Figs. 2, 46, 47, and 48 the statistics of Munich, Frankfort on the Main, Warsaw, and Danzig. The diagrams do not need explanation. Undoubtedly other circumstances may have had something to do with this reduction, such as better care of the sick,

* See Reports of Mich. State Board of Health; also paper by Prof. W. P. Mason on "Rainfall and Typhoid Fever," Jour. Franklin Institute, Sept. 1895.



Diagrams showing reduction in typhoid-fever death-rates following introduction of pure water and sewers.

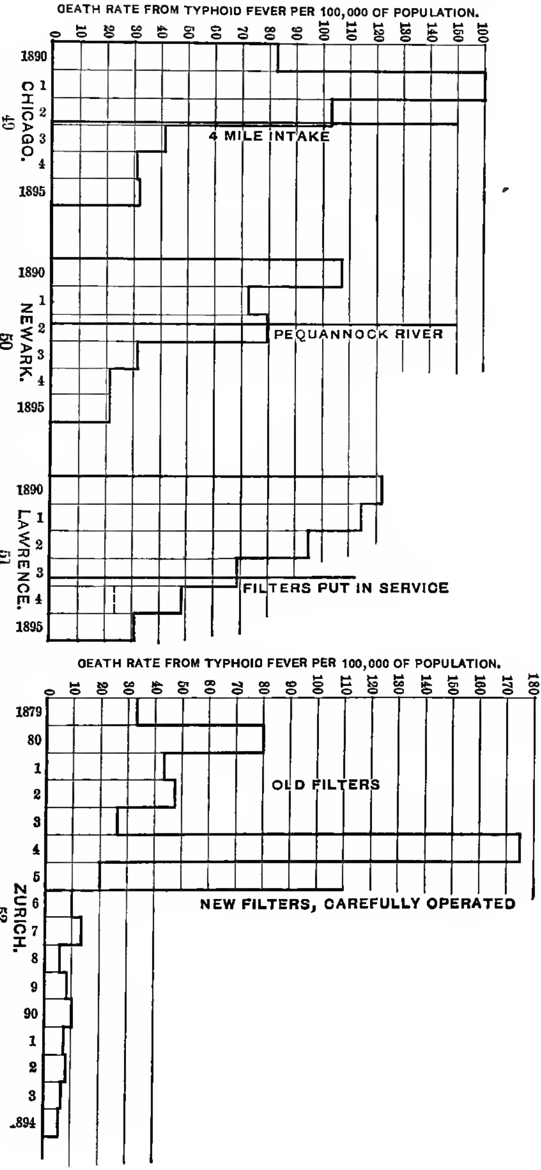
due to more knowledge of the nature of the disease and improved methods of treatment; but the effect is marked and positive in each case.

IV. Effect of Pure Water alone upon Typhoid-fever Death-rates.

The reduction of the death-rate from typhoid fever following upon the improvement in the quality of water supplied, in cities which are fully sewered and drained, is shown in many places in this country and Europe. Immediately after the change to the "four-mile intake" at Chicago in 1893, Fig. 49, there was a great reduction in typhoid. The city of Newark, Fig. 50, shows a great improvement when the new supply was introduced from the Pequannock, April 12, 1892. Hamburg, Fig. 3, shows an improvement with the placing of the filters in operation in May, 1893. Lawrence, Mass., Fig. 51, shows a great improvement with the setting of the filters in operation in September, 1893; fully half of the deaths in 1894 were among persons known to have used the unfiltered canal-water. In Zurich, Fig. 52, with the intelligent operation of the filters since 1885, the typhoid death-rate has been almost constant and very low.

Dr. Reincke says, in regard to Hamburg,* that the evidence that the reduction of typhoid in that city has been the result of an improvement in the water, is

* "Zur Epidemiologie des Typhus in Hamburg und Altona" (see note, page 3).



Diagrams showing a reduction in the typhoid-fever death-rates following an improvement in the quality of the drinking-water.

substantiated by the typhoid among the shipping interest in the harbor, where the raw water is used, remaining as great as it was before, whilst in the city, where filtered water is used, it has fallen from 90 per 100,000 in 1887 to 6 in 1894 and 9 in 1895. He also reasons that the typhoid-fever infection has always come through the same channels that have brought the cholera, and shows by a tabular statement, quoted below, that the maximum of typhoid fever has followed two to three weeks later than the maximum of cholera.

In 1892 and 1893 there were sick—	From Cholera.	From Typhoid.
In the week from Aug. 14 to 20	115	42
" " " " " 21 to 27	3593	38
" " " " " 28 to Sept. 3	6157	69
" " " " Sept. 4 to 10	3217	139
" " " " " 11 to 17	2092	155
" " " " " 18 to 24	1224	132
" " " " " 25 to Oct. 1	393	78
" " " " Oct. 2 to 8	101	76
" " " " " 9 to 15	41	52
" " " " " 16 to 22	14	43
" " " " " 23 to 29	1	34
" " " " " 30 to Nov. 5	3	32
" " " " Nov. 6 to 12	5	21
" " " " Dec. 4 to 10	4	15
" " " " " 11 to 17	3	14
" " " " " 18 to 24	18	18
" " " " " 25 to 31	18	19
" " " " Jan. 1 to 7, 1893	4	27
" " " " " 8 to 14	9	32
" " " " " 15 to 21	6	14

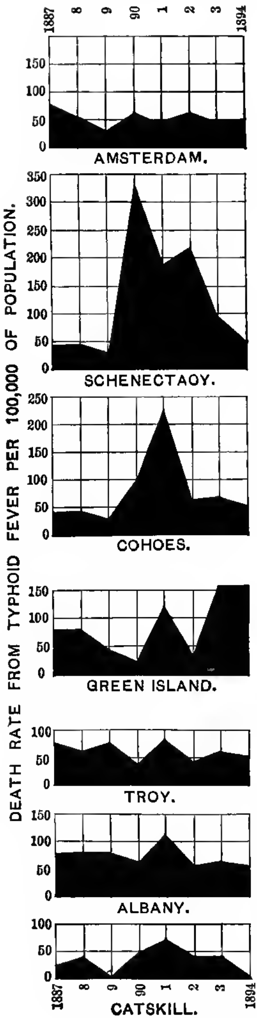
The same phenomena were observed in 1893, when the raw water of the Elbe broke into the pipes delivering the filtered water; and he concludes that the lapse

of the two or three weeks in each of these cases represents the difference in the periods of incubation of the two diseases, and that if the cholera comes from the drinking-water, the typhoid fever also does.

V. Effect of Waters known to be Polluted upon the Typhoid-fever Death-rates.

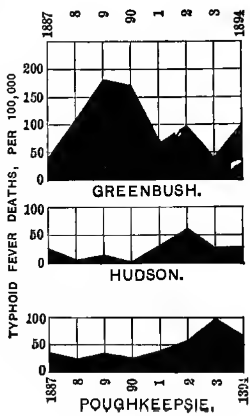
Some of the large towns on the Mohawk and Hudson rivers have an interesting history in the light of these statistical studies; they have already been reported on in connection with local epidemics. There is, however, another side of the question that has not, to my knowledge, received attention heretofore, and that is the yearly fluctuations of the typhoid-fever death-rates. In Figs. 53 to 62 are given the death-rates of Amsterdam, Schenectady, Cohoes, Green Island, Troy, Albany, Greenbush, Catskill, Hudson, and Poughkeepsie, cities on the Mohawk and Hudson rivers, from 1887 to 1894, inclusive. The distances between the towns are approximately as follows: Amsterdam to Schenectady, 17 miles; Schenectady to Cohoes, 17 miles; Cohoes to Troy, 3 miles; Troy to Albany, 6 miles; Albany to Catskill, 31 miles.

By observing the yearly rates for Amsterdam and Schenectady, it will be seen that they have varied in the same direction since 1887, Schenectady exhibiting the most violent fluctuations. Schenectady drinks the Mohawk River water polluted with the Amsterdam sewage. Also, the curves for Cohoes, Green



DIAGRAMS SHOWING THE SYNCHRONOUS FLUCTUATIONS OF THE TYPHOID FEVER DEATH RATE IN CITIES ON THE MOHAWK AND HUDSON RIVERS, WHICH ARE SUPPLIED WITH DRINKING WATER FROM THESE RIVERS

Figs. 53 to 62.



Island, Troy, Albany, and Catskill show a very remarkable parallelism. Troy drinks the water of the Hudson opposite Waterford, but West Troy drinks the Mohawk water taken at a point above Cohoes. Cohoes drinks the Mohawk water taken just above the town, and Albany and Catskill drink the water of the Hudson. The Troy water should be comparatively free from sewage contamination, and therefore cannot be blamed for this unusual typhoid mortality; the probable reason why Troy reports so many deaths being, as Dr. John H. Cipperly, health officer, suggests, that many cases of typhoid from West Troy, Cohoes, Green Island, and other neighboring places are sent to the Troy hospitals, and the deaths may thus be reported from Troy. The high typhoid death-rates in Amsterdam and Schenectady in 1890 were caused by a sharp epidemic lasting from July, 1890, to April, 1891, having its greatest severity in the latter part of 1890, while during the same epidemic the greatest severity in Cohoes and the other cities down the river was in the early part of 1891. This, I think, explains why the curves for Cohoes, Troy, and Albany are apparently a year after the curves for Amsterdam and Cohoes, and makes it possible to recognize the similarity in all of them.

In view of this explanation, and of the possibility of the bacterium of typhoid fever retaining its vitality in water, even at the temperature of freezing,* for a

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* Mass. State Board of Health, 1890. Typhoid Fever in its

much longer time than would be necessary for its transference from any of these towns to the one below through the medium of the river; of the fact that all these cities drink the waters of the Mohawk and Hudson rivers, polluted with the sewage of the cities above; of the fact that their typhoid-fever death-rates have fluctuated synchronously year by year, while cities on the other side of the river below Troy, where the effect of the large volume of pure water from the upper Hudson is felt, do not fluctuate synchronously with those polluted by the Mohawk waters; of the fact that the bacteriological analyses* of the river-water have shown a large increase in bacteria below each city, the number decreasing with the dispersion of the sewage by down-stream flow, but remaining above normal as compared with the water above Rome, I think we may safely conclude that we have here an undoubted case of the propagation of typhoid fever through the drinking-water.

VI. Relation between the Quality of Water Supplied to a City and the Death-rate from Typhoid Fever.

If the drinking-water supplied to cities is an index of their healthfulness as measured by the typhoid-fever death-rates, we should expect to find some sort

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Relation to Water-supplies, Hiram F. Mills, A.M., C.E., pp. 525–543. Prudden has shown that they can retain their vitality in ice for 103 days.

* N. Y. State Board of Health, 1892, p. 533.

of relation existing between the quality of the water and the typhoid death-rates. Of course it is unreasonable to expect to find such an exact relation that there would be no variation from the rate for each different classification; there must be overlapping, as local conditions may make a certain water more subject to pollution than another. As a general thing, we should expect to find that cities whose water is kept perfectly secure from contamination, such as use spring-water secured in mountains where no pollution is possible, would have the lowest death-rates, and the range of fluctuation would be very small, comparatively speaking. Next we should expect to find that water properly filtered, as is done extensively in Europe, would show a low rate and one without much fluctuation, provided the operation is carefully and intelligently carried on. Next in purity we should expect to find groundwaters, and in these there might be accidental pollution that would cause considerable fluctuation. Then follow, in the order of their liability to contamination, large impounding reservoirs, where legal measures are taken to restrict pollution; large rivers, either normal, or where great volume and absence of any considerable evident place of pollution within a great distance, coupled with dispersion, sedimentation, and nitrification, may have brought a previously polluted river back to its normal condition. Then follow great lakes, whose waters at great distances from polluting sources are pure, but which are liable to pollution near the shores (in this class, from the relative positions of the intakes, we should expect to find rates varying from

those of a very healthful city to those of the most infected); upland streams and small gathering-grounds where no special precautions may be taken to restrict pollution of the watersheds; and, finally, rivers and sources known to be polluted with sewage. In cities using such supplies we should expect to find high typhoid-fever death-rates, and a considerable variation of rates from year to year.

In order to investigate this, I have collected and tabulated the typhoid-fever death-rates of a great number of cities, both in Europe and America, for the years 1890–1895, inclusive when possible, with a total population of about 33,300,000. For the six years these statistics would therefore represent the typhoid-fever mortality of nearly 200,000,000 people. Many cities which I wished to add to this list, I regret to say, have been unable to furnish me with the desired information. I have not included any cities in the United States of less than 50,000 inhabitants, and in Europe I have selected only large well-known cities. Doubtless many more could be added to the list, but I have considered that for the purposes of this study the data presented are sufficient.

In some respects it might be of advantage to use the sick-rate, rather than the mortality-rate, but it cannot always be obtained, and the latter has some merits not possessed by the former.

The different qualities of water I have placed in the following classes:

Class A. Mountain springs with sources undoubtedly beyond the danger of pollution.

Class B. Waters properly purified by slow sand-filtration.

Class C. Pure ground-water supplies.

Class D. Surface-water supplies with large impounding reservoirs and legal provisions against pollution.

Class E. Large normal rivers, or rivers in which the pollution may be considered to have greatly vanished through the agency of sedimentation, dilution, and other causes.

Class F. Large inland lakes, which may be more or less subject to pollution.

Class G. Upland streams and small lakes with limited watersheds which are more or less inhabited.

Class H. All rivers and public and private wells which are known to be polluted with sewage and other infectious matter to varying degrees.

In order to distinguish between the different classes of water it was necessary to establish arbitrary standards which would with more or less definiteness afford a means of deciding in doubtful cases. In the cases of spring-waters, filtered waters, ground-waters, impounded waters, large-lake waters, and upland streams there was no difficulty; but to make it possible to decide whether a river should be classed as normal or as polluted, it was necessary to have a standard.

The classification which I have made is based upon the following considerations:

For a water to be classed as normal it is necessary that—

1. The intake of the water-works should be so

located as to be above the influence of the discharge of either sewage or surface drainage from the urban or suburban districts of the city.

II. There should be no city up-stream discharging crude sewage into the river within such distance that the sewage would not be thoroughly and completely dispersed throughout the cross-section of the river before reaching the water-works intake. This distance I arbitrarily fixed at 10–30 miles, according to the size and character of the river.

III. The proportion of sewage from the whole watershed above the city in question to the ordinary dry-year flow of the river should not be more than about as 2½ to 1000. This dilution at *low water* will give a water containing probably several times as many bacteria per cubic centimetre, after thorough dispersion by several miles of flow, as would be considered advisable for a drinking-water, but for the *average flow* of the stream it might not be considered unfit for use. The average of seven authoritative German standards * makes the dilution required to render urine safe for potable uses 2 parts in 1000. The effect of the sedimentation of the bacteria by their adherence to heavy particles would tend to reduce the number in suspension, particularly if the water should be drawn off from the surface.

Only towns on the rivers or their tributaries are considered in these calculations, the strictly rural population being neglected. All the sewage from

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* Baumeister.

towns with sewers, and 30 per cent of the sewage from towns without sewers, is assumed to ultimately reach the river. The amount of sewage generated is assumed for American towns to be equal to 60 gallons per capita per diem.

These arbitrary assumptions are not offered as models for absolute standards; they are intended only to furnish a means of making a classification of waters as they are found, which would be based upon extant and comparable conditions. There are so many complex phenomena met with in cases of river pollution that probably no definite standard can be adopted, excepting to consider all natural waters as polluted to greater or lesser degrees, mountain spring-waters and properly filtered waters being the least so.

Cities supplied with the water of lowland rivers, but having a large or considerable population supplied with public and private wells, are classed with polluted supplies. Among the cities so classed are Washington, Louisville, and Atlanta.

Applying the conditions stipulated above to certain doubtful cities, the results are exhibited in the following tabulation.

These figures are not considered to represent the actual amount of sewage discharged into the various streams, but they afford a means of making a comparison between them. There is great probability that in all the streams quoted the pollution is greater than I have estimated it.

No allowance has been made for the disappearance of bacterial pollution, because there is good reason to

Name of City.	River forming Supply.	Area of Watershed, Square Miles.	Minimum Flow, Cu. Ft. Sec.	Ordinary Low-year Flow, Cu. Ft. Sec.	Estimated Population contributing Sewage.	Estim. Sewage Flow to Rivers, Cu Ft Sec.	Parts of Sewage per 1000 parts of River-water. Min. Flow.	Parts of Sewage per 1000 parts of River-water. Dry-year Flow.
Albany.......	Hudson	8,200[1]	2.000[1]	3,000[5]	500,000	37	18.5	12.3
Atlanta	Chattahoochee.	2,000[6]	500[6]	1,000[5]	10.000	1	2.0	1.0
Camden	Delaware......	8,100[2]	1,500[5]	2,000[3]	190,000	18	12.3	9.0
Columbus....	Scioto........	1,139[4]	25[4]	—	—	—	—	—
	Olentangy .	547[4]						
GrandRapids	Grand	2,500[6]	375[5]	500[5]	25,000	1.5	4	3
Indianapolis.	White.	1,500[6]	300[6]	400[6]	40,000	2.0	6.7	5
Jersey City..	Passaic	950[6]	225[8]	400[6]	400,000	37	166.7	90.9
Louisville....	Ohio...........	91,000[7]	7,750[7]	—	1,250,000	74	9 5	—
Newark	Passaic	950[6]	225[8]	400[5]	190,000	18	83.3	45.5
Paterson ...	Passaic	800[8]	150[8]	287[9]	18,000	.5	3.3	1.7
Philadelphia.	Delaware.....	8,100[10]	1,500[6]	2,000[6]	190,000	18	12.3	9.0
"	Schuylkill.....	1,800[11]	350[5]	600[5]	120,000	11.0	31.3	18.2
Pittsburg ..	Allegheny .	11,107[12]	1,330[12]	2,000[6]	170,000	13	10	6.5
Richmond ..	James	6,800[13]	1,300[13]	1,750[13]	80,000	5	3.8	2.8
Toledo.......	Maumee. .. .	6,723[14]	1,000[6]	3,000[6]	120,000	7.5	7.5	2.5
Trenton......	Delaware	6,916[16]	1,000[16]	2,700[17]	144,000	4	4	1.5

[1] N. Y. State Board of Health, Rep't 1892. [2] Geological Survey of N. J., vol. III. 1894, a.58. [3] Geological Surv. N. J., vol. III. 1894, p. 309. [4] Tenth Census U. S., Water Power, vol. II. p. 476. (This gauging taken 60 years ago No recent gauging. With this minimum flow a population of 1000 above Columbus would pollute beyond the limits established.) [5] Estimate. [6] Tenth Census U.S, Water Power, vol I. p. 650. [7] Tenth Census U S, Water Power, vol. II. p. 440. [8] Geol. Surv. N. J. 1894, vol. III. p. 103. [9] Tenth Census U. S, Water Power, vol. I. p. 650. [10] Allen Hazen, Report on Filtration of Philadelphia Water-supplies, 1896. [11] Geol. Surv. N. J. 1894, vol. III. p. 104. [12] Tenth Census U. S., Water Power, vol. II. p. 442. [13] Tenth Census U. S., Water Power, vol I. p. 536. [14] Tenth Census U. S, Water Power, vol. I. p. 495. [15] Geol. Surv. N. J. 1894, vol. III. p. 229. [16] Geol. Surv. N J. 1894, vol. III. p. 241. [17] Tenth Census U. S., Water Power, vol. I. p. 613.

believe that usually the effect of sedimentation and oxidation have been largely overestimated, and that what has been attributed to these causes has more generally been due to perfect dispersion. The complete sedimentation of all bacteria * by gravity is an

* N. Y. State Board of Health; Report of C. C. Brown on Experiments on Sedimentation of Bacteria in St. Louis Settling-tanks.

impossibility in any finite period of time; in flowing streams, even when carried down by precipitants, the bacteria may soon rise again when freed from their weighted envelope by currents in the liquid. The currents in rivers * induced by the rugosities of the bottom, differences of temperature, and other causes are sufficient to maintain in suspension or keep in motion bodies of far greater weight than these; and under even very adverse conditions they may be transported by flowing waters to very great distances without losing their vitality. As before stated, probably the most potent factor in the apparent disappearance of bacteria in large reservoirs is the more perfect dispersion of the inflowing water throughout the whole mass of impounded water than could take place in many miles of flow in a stream, because the motion of water in rivers is filamentary to a certain extent. A very good illustration of the more perfect dispersion that takes place in a reservoir of quiet water than in a flowing stream is afforded by the river Rhone in Switzerland. Where its gray glacial waters empty into Lake Geneva the whole end of the lake is discolored by the dispersion of the finely divided suspended matter in every direction. Where the river issues from the other end of the lake it is a beautiful clear blue color, and in the suburbs of the city of Geneva it is joined by the river Arve, whose muddy

*A valuable article on the "Suspension of Solids in Flowing Water" was presented before the American Society of Civil Engineers, Sept. 2, 1896, by Elon Huntington Hooker, Ph.D., C.E.

waters issue from beneath the glaciers of Mont Blanc. These two large rivers then flow side by side in the same channel for a great distance without appreciable intermingling of their waters.

The flow of discolored sewage in clear streams is also an illustration in point. I have seen the dark-brown water from one of the sewers in Munich form a stream 5 to 10 feet wide in the clear Isar, and be perfectly distinguishable after a flow of nearly a thousand feet.

Under the classification given on pages 15 and 16, the different cities quoted in Appendices A and B would be grouped as follows:

Mountain Springs.—Munich and Vienna.

Filtered Waters (slow filtration through sand, and not mechanical filtration or straining).—Amsterdam, Berlin, Breslau, Buda-Pesth (until 1894), Edinburgh, Hague, Hamburg (since May, 1893), Lawrence (since September, 1893, but the canal-water is still sometimes used in the mills), London, Rotterdam, Warsaw, and Zurich.

Ground-waters.—Brussels, Buda-Pesth (since 1894), Copenhagen, Dayton, Dresden, Frankfort on the Main, Lincoln, Neb., Lowell, Mass. (since February 22, 1895), Paris, Venice (since 1890).

Impounding Reservoirs.—Baltimore, Boston, Brooklyn, Cambridge, Fall River, Glasgow, Liverpool, Manchester, Newark (since April 12, 1892), New Haven, New York, Rochester, Sydney, Syracuse (since July 3, 1894; there are still many wells used in Syracuse), Worcester.

Large Normal Rivers.—Minneapolis, Montreal, New

Orleans, Omaha, Paterson, Quebec, St. Louis, Toledo, Trenton.

Large Inland Lakes.—Buffalo, Chicago, Cleveland, Detroit, Hamilton, Ont., Milwaukee, Toronto.

Upland Streams, Small gathering-grounds and Springs in Populous Valleys.—Denver, Genoa, Hartford, Providence, Reading, Rome, San Francisco, Scranton, St. Paul, Syracuse (until July 3, 1894), Wilmington.

Polluted Rivers and Wells.—Albany, Alexandria (Egypt), Allegheny, Atlanta, Cairo (Egypt), Camden, Cincinnati, Columbus, Grand Rapids, Hamburg (till May, 1893), Indianapolis, Jersey City, Lawrence (until September, 1893), Louisville, Lowell (till February, 1895), Newark (till September 12, 1892), Philadelphia, Pittsburg, Richmond, Troy, Washington, D. C.

The typhoid-fever death-rates per 100,000 for all these cities for the years 1890 to 1895, inclusive, when obtainable, are given in Appendix A.

In Figs. 63 to 68 I have shown graphically these death-rates per 100,000 for each of these cities for the years 1890 to 1895, inclusive. The different cities are grouped in classes according to the quality of the water supplied to them. I have preferred to plot the statistics for each year separately, rather than to take averages for the six years.

It will be noticed that there is a decided tendency toward high death-rates in the cities using supplies of a questionable character. The lowest rates are toward the pure-water end of the diagrams; and while there is an overlapping of rates, as it were, they sub-

stantiate entirely what has been premised would be the case.

In Appendix D will be found a table containing a statement of the number of times a given death-rate from typhoid fever recurs in all these cities when classified according to the qualities of their water-supplies, and from this table it can be calculated—

that in the cities using *filtered water* 94% of the death-rates per 100,000 are more than 3, 83% are less than 20, and 77% are between 3 and 20;

that in cities using *ground-waters* 98% of the death-rates per 100,000 are more than 5, 77% are less than 32, and 75% are between 5 and 32;

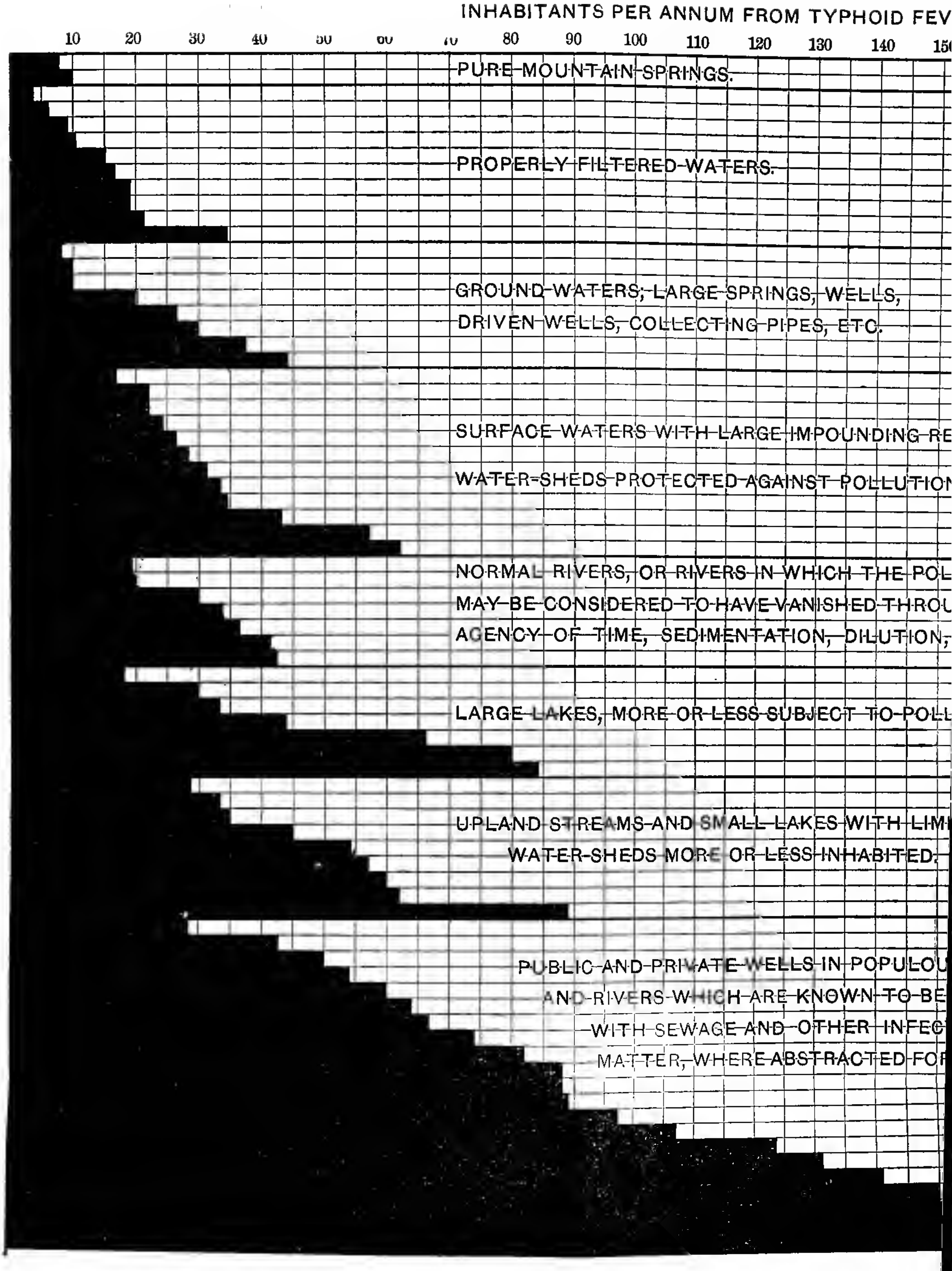
that in cities using *impounded waters* 97% of the death-rates per 100,000 are above 15, 80% are less than 35, and 77% fall between 15 and 35;

that in cities using the *waters of large normal rivers* 90% of the death-rates per 100,000 are above 17, 85% are less than 38, and 75% are between 17 and 38;

that in cities using the waters of the *great lakes* 93% of the death-rates per 100,000 are over 18, 80% are less than 54, and 73% are between 18 and 54;

that in cities using the waters of *upland streams, etc.*, 92% of the death-rates per 100,000 are over 29, 80% are less than 58, and 72% are between 29 and 58;

that in cities using *polluted waters* 95% of the death-rates per 100,000 are over 40, and only 65% fall between 50 and 100, the upper limit frequently exceeding 300.



INHABITANTS PER ANNUM FROM TYPHOID FEV
10
20
30
40
50
60
70
80
90
100
110
120
130
140
PURE MOUNTAIN SPRINGS.
PROPERLY FILTERED WATERS.
GROUND WATERS; LARGE SPRINGS, WELLS,
DRIVEN WELLS, COLLECTING PIPES, ETC.
SURFACE WATERS WITH LARGE IMPOUNDING RE
WATER-SHEDS PROTECTED AGAINST POLLUTION
NORMAL RIVERS, OR RIVERS IN WHICH THE POL
MAY BE CONSIDERED TO HAVE VANISHED THROU
AGENCY OF TIME, SEDIMENTATION, DILUTION,
LARGE LAKES, MORE OR LESS SUBJECT TO POLL
UPLAND STREAMS AND SMALL LAKES WITH LIM
WATER-SHEDS MORE OR LESS INHABITED.
PUBLIC AND PRIVATE WELLS IN POPULOU
AND RIVERS WHICH ARE KNOWN TO BE
WITH SEWAGE AND OTHER INFEC
MATTER, WHERE ABSTRACTED FOF

FIG. 64 DEATH RATES PER 100,000 INHABITANTS PER ANNUM FROM TYPHOI

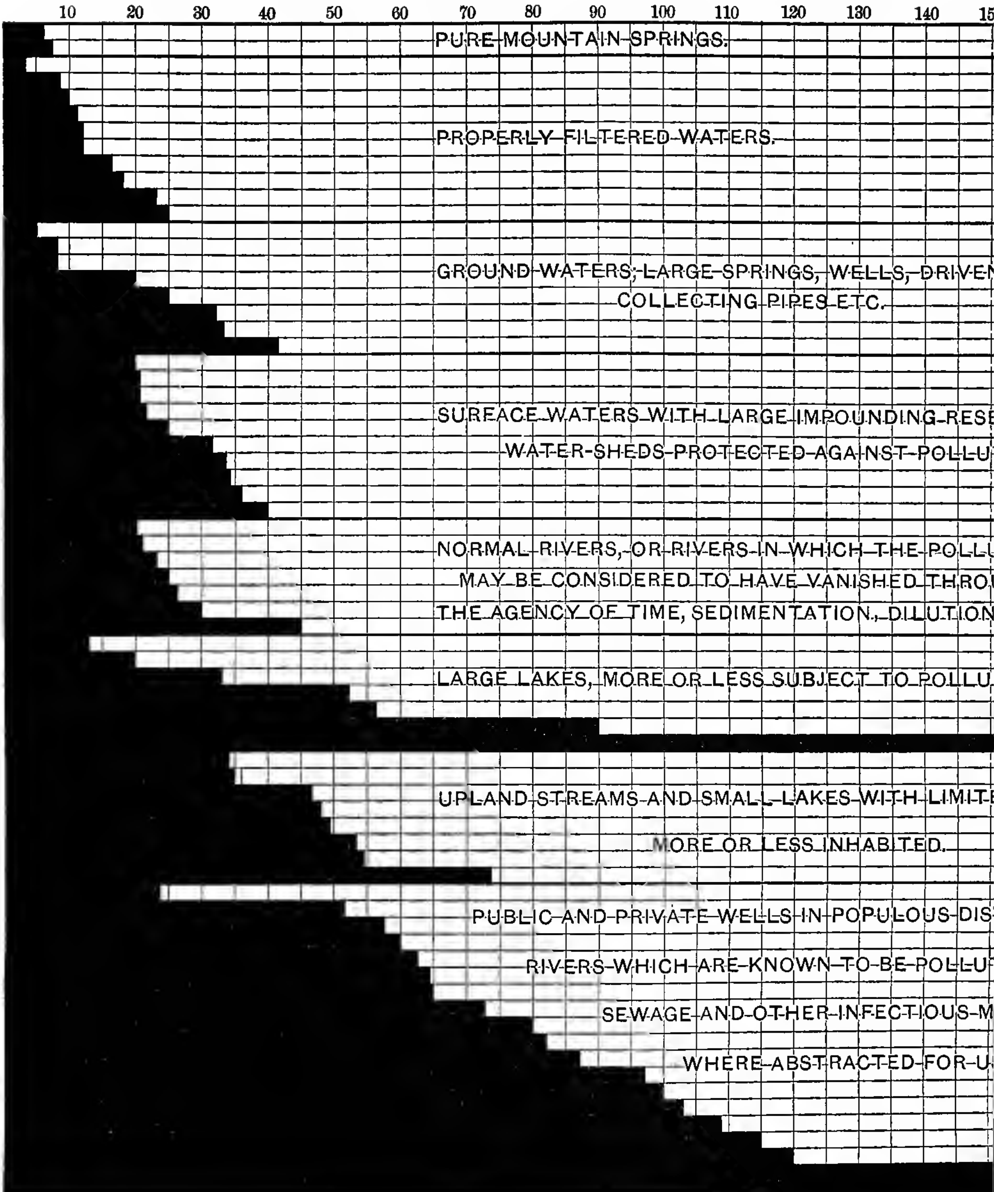


FIG. 65 DEATH RATES PER 100,000 INHABITANTS PER ANNUM FROM TYPHOID FEV

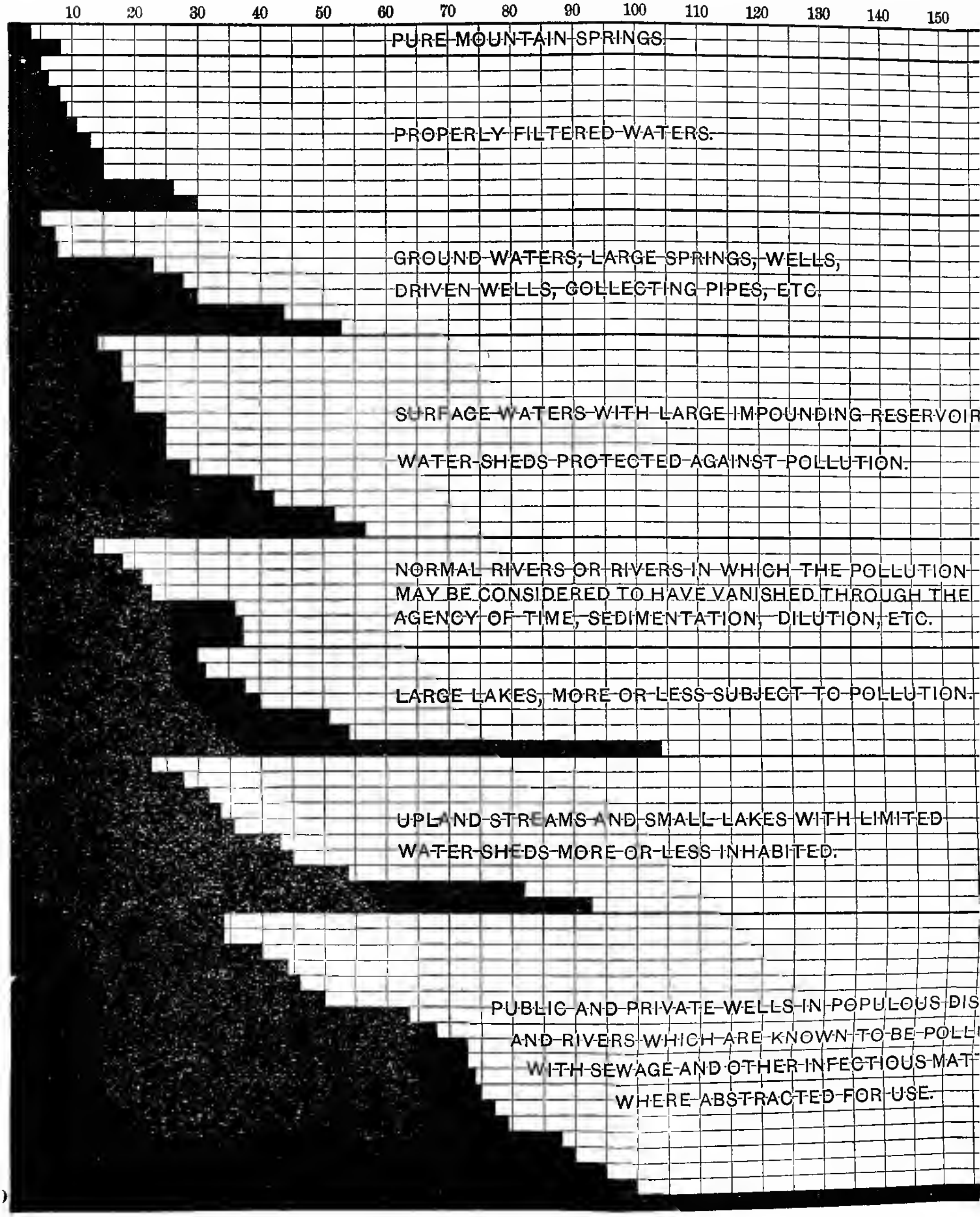
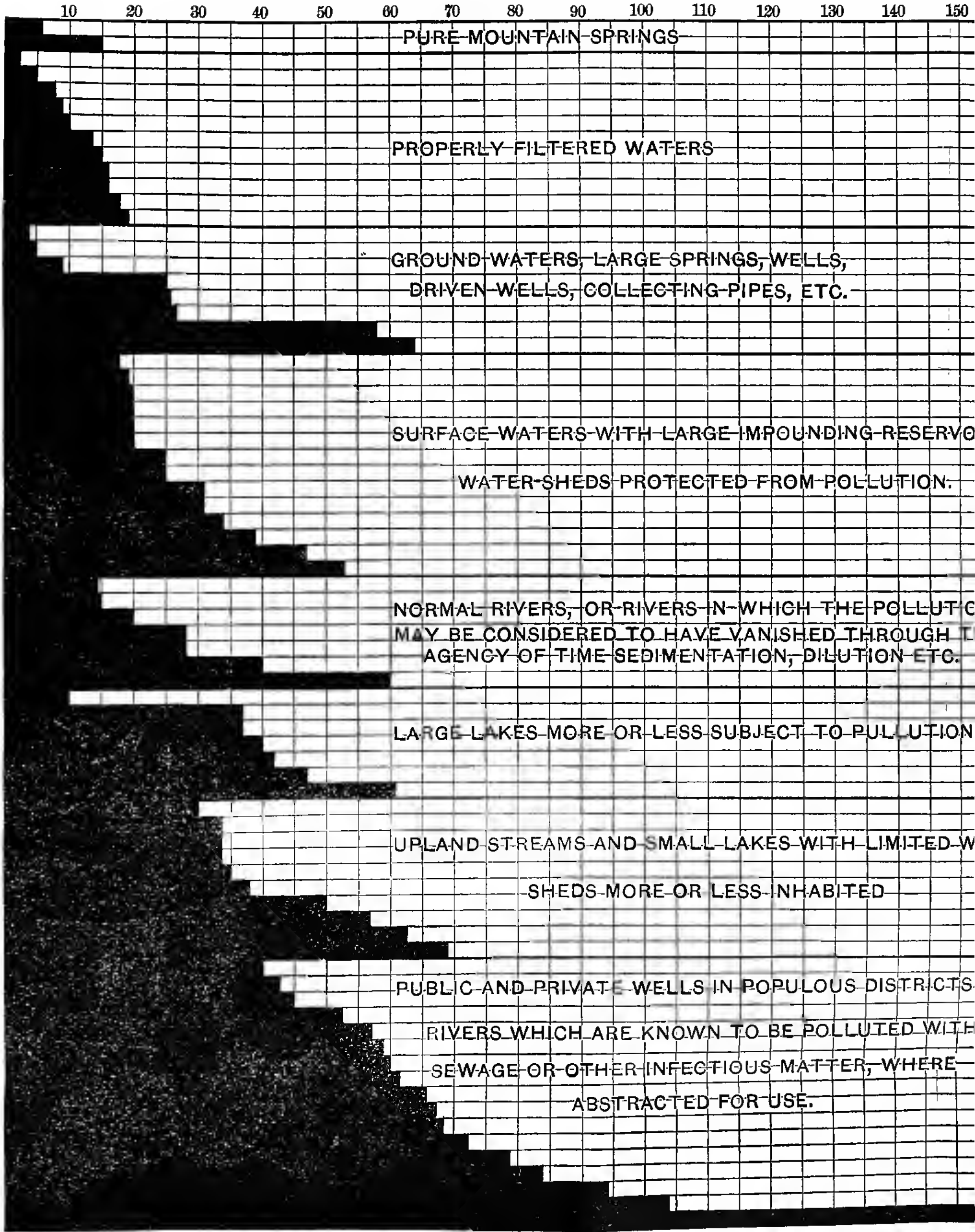
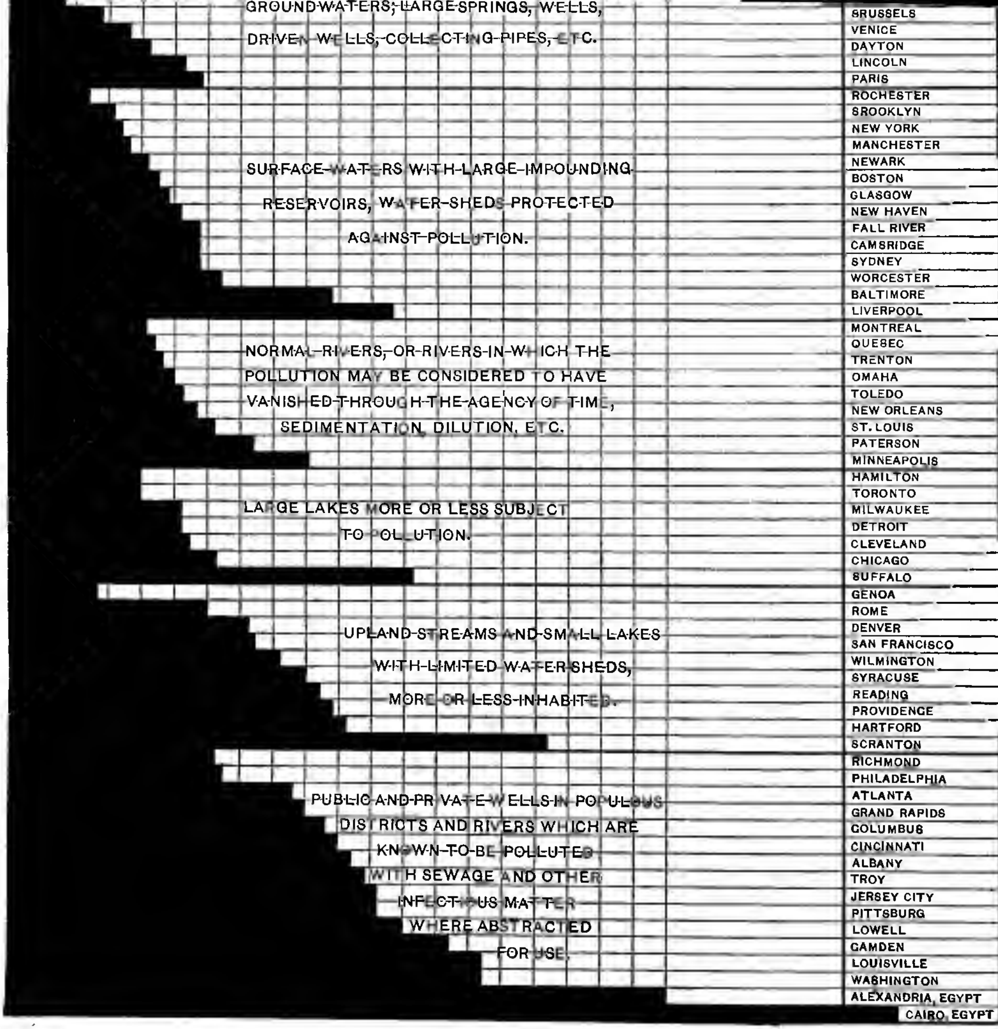


FIG. 66 DEATH RATES PER 100,000 PER ANNUM FROM TYPHOID FEVER

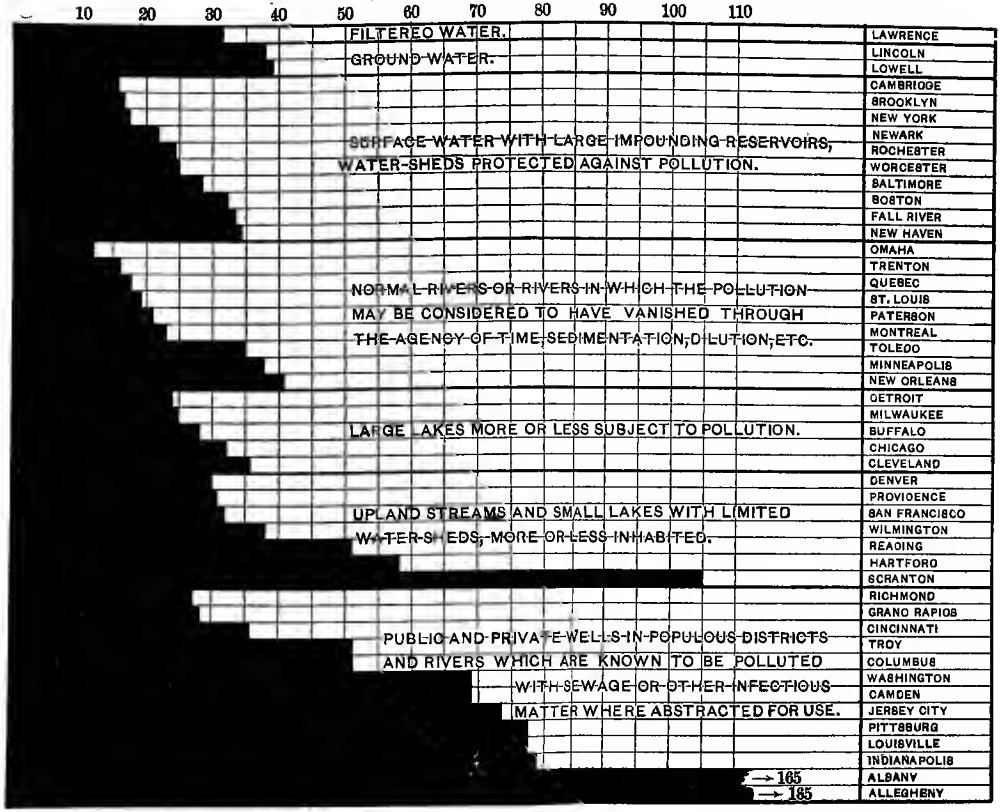


* This typhoid was attributed to sewage pollution coming from the discharge of a large sewer ju
the intake was moved up to the new works above the city.

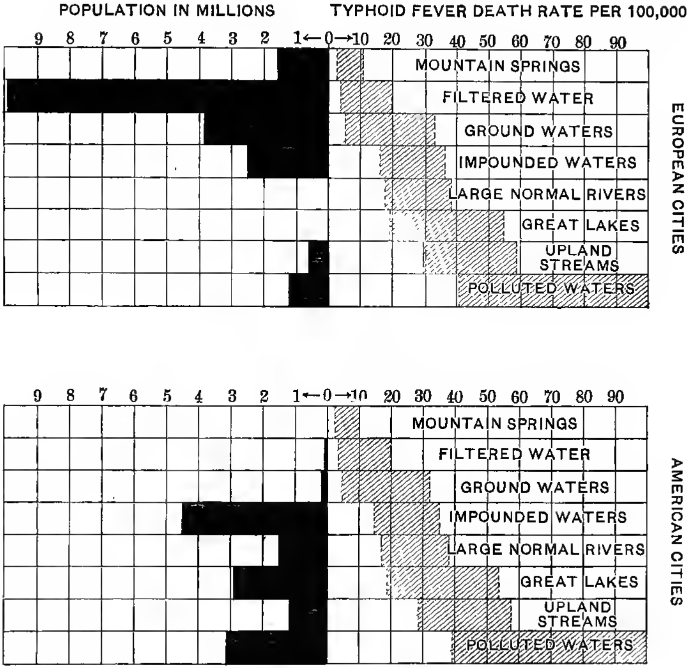


(To face page 32.)

FIG. 68 DEATH RATES PER 100,000 INHABITANTS PER ANNUM FROM TYPHOID FEVER IN 1895.



(To face page 32.)



Diagrams showing the limits between which 75 per cent of the typhoid-fever death-rates per 100,000 per annum fall, and the distribution of population using the different classes of water in Europe and America in the cities contained in Figs. 63, 64, 65, 66, 67, and 68.

In order to present another view of the meaning of these figures, I have shown in Figs. 69 and 70 the limits between which 75 per cent of the death-rates per 100,000 may be expected to vary in the cities we have used for the different classes of water, and the population using each class. The population of all the cities aggregates about 33,300,000, of which 13,300,000 are in America and 20,000,000 are in foreign countries. In Fig. 71 I have plotted the total population of the American cities, showing the distribution of population as to the quality of water-supply, and in Fig. 70 the same information is given for the European cities. They show that nearly all our supplies are from sources which are subject to pollution. In the foreign cities we find over 15,500,000 people using waters that are pure, 2,500,000 people using waters ranking with our best supplies, and about 2,000,000 using polluted waters.

These diagrams also show graphically that more than 75 per cent of the total population of the European cities included in this study are supplied with water of a better quality than that from impounding reservoir supplies, of which New York is typical, while in the United States more than 75 per cent are supplied with water of a poorer quality than that from impounding reservoirs. The grouping of the European populations at the pure-water end of the diagram, with the low typhoid death-rates, is not accidental. All of these cities have had their lessons, and have at one time had rates as high as or higher than our cities have at present. They are now drained and sewered and

provided with pure water. This change in their condition in this respect cannot be attributed entirely to lowering the ground-water level, for in such cities as Zurich, Frankfort, Hamburg and Altona, whose statistics showed formerly a high and variable rate while possessed of complete and efficient sewerage, there has been an absolute and permanent reduction of the death-rate from typhoid fever upon the introduction of pure water. The effects of climatic and meteorologic conditions also have been eliminated in these cities.

The same statements seem to be true of our large American cities, and the conclusion is warranted that for the efficient control of the death-rate from typhoid fever it is necessary to have efficient sewerage and drainage, proper methods of living, and pure water. The reason why our large cities, which are all provided with sewerage excepting Baltimore (which has now under advisement a scheme for sewage disposal), have such high rates is therefore without doubt their continuance of the filthy practice of supplying drinking-water which carries in solution and suspension the washings from farms, from the streets, from privies, from pig-pens, and the sewage of cities.

CHAPTER II.

WHEN DOES PURE WATER PAY?

TO decide what waters can be considered pure is therefore frequently very difficult, because the question of purity is a relative one. Large populous communities can afford to spend more money in seeking a pure water than small ones, and it becomes an economic question to determine how much can be expended in this way in any given case.

From a study of the many successful filtration plants of Europe and the splendid results of the Lawrence experiments conducted by the Massachusetts State Board of Health, I think it is accepted as a fact that properly designed and operated filters may be relied upon to purify any waters at present used for a public water-supply in the United States.

Apart from humanitarian and æsthetic views, pure water can easily be shown to be desirable from the standpoint of social economy. Of course there are many other diseases of which statistics are not available which would be favorably affected by an improvement in the water-supply, so that the benefits to be derived would be greater than merely a reduction of the typhoid-fever death-rates.

It is very difficult to demonstrate in a way that can be readily appreciated whether it pays for a community to endeavor to reduce its death-rate by such means, because the expenditure is made to procure an anticipated benefit, a presumptive insurance which the individual can enjoy only in the consciousness that his chances of being stricken down by disease or death are lessened. It is not like the expenditure for parks, boulevards, and baths, which are sources of pleasure, or for sewerage or water-works, where the expense incurred when undertaken by the community results in better service and greater comforts, which would often be out of reach of the individual, for less actual outlay per capita than if they were not undertaken. Purification of the water is an improvement; it is attended by increased cost; and the benefits are to redound to the community at large. The individual, who is accustomed to ordinary hazards and risks, may feel satisfied that, as he has escaped death from water-carried diseases thus far, he will be equally fortunate in the future, and he may not feel that the increased expense will be counterbalanced by the security promised. In this question we must, however, take a broader view; we must not stop at the individual, but must consider the benefits to the entire community. If these questions were left to the ignorant, or affected the ignorant alone, nothing would be done to better our conditions, and our populations would soon share the fate that overwhelmed the greater part of Europe during the middle ages. There are many epidemics of typhoid fever on record in which the

greatest severity has been confined to the wealthiest portions of the cities, and it is therefore manifest that the interest of the educated people should be awakened to the true importance and significance of the protection of the purity of the water we drink.

Generally about 9 to 12 per cent of the typhoid-fever cases are fatal, and the majority of the fatalities are among people in the prime of life, children and old persons being less frequently attacked. This fact is of importance, because it shows that the fatality is greatest among the wealth-producers, whose deaths are a direct loss to the community.

Rochard gives as the economic value of an individual the sum "that he has cost his family, the community, or the state for his living, development, and education. It is the loan which the individual has made from the social capital in order to reach the age when he can restore it by his labor." This has been variously estimated at from $1000 to $5000. In view of the fact, before stated, that frequently the highest mortality rate is among the prosperous classes, it will not be too high a figure to assume $3000 as the average value of such a life. Therefore under such assumption each death represents the abstraction from the community of the earning power of about $3000 of capital. The community therefore can evidently afford to invest this sum for every death forefended, provided enough may be prevented each year to pay the interest and sinking-fund charges on the sum required to install the necessary works and to operate them.

The cost of filtering a water-supply depends upon many conditions of a local nature. Small plants will cost more in proportion for construction and operation than large ones. Plants in cold countries may cost more than plants in warm countries. Plants for waters containing much suspended matter will cost more than plants for clear waters; and in any case it is only a matter of estimate to determine what the cost of construction and operation of a plant will be for principal and for annual charges. It is then very easy to tell whether filtration will pay. Allen Hazen says* that a reduction of the annual death-rate by 7 will warrant the construction of filters when a life is valued at $5000, and that a reduction of 70 will save enough to the community in one year to pay for the construction of the plant. These statements are based upon estimates for a city of 100,000 people. In cities in warm climates, with waters ordinarily not heavily charged with sediment, the cost of construction and operation may be, under favorable conditions, only about one half of these estimates, and the saving of four lives at $5000 each, or six lives at $3000 each, per year in a city of 100,000 people would be justifiable, in that their value would be more than the annual charges necessary to maintain the works and refund the capital.

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* Hazen, "Filtration of Public Water-supplies,"

CHAPTER III.

SANITARY VALUE OF IMPOUNDED AND OTHER SUPPLIES.

It is sometimes said that the typhoid-fever death-rates in New York City, Boston, Brooklyn, and other cities with similar supplies, are independent of any infection coming from the water; that most or all the typhoid in them is imported. These data do not of course afford sufficiently detailed information to dispute that assertion; but if such be the case, it is difficult to understand why the rate should be so high. From all parts of the world the typhoid death-rate in cities using this class of water is about the same, and higher than in cities using a purer or more perfectly protected water. It may be said that the American populations are more shifting than those of European countries, and they thus keep importing cases into the cities from the country districts more than the Europeans do. This criticism, however, is met by offering the statistics of Liverpool, Glasgow, and Manchester, with impounded supplies, in comparison with those of London and Edinburgh with filtered supplies, and we are compelled to acknowledge an advantage in favor of the latter.

The relative purity of different classes of water as found in nature in the neighborhood of large cities is thus apparently responsible for a large proportion of the typhoid fever. The local epidemics caused by infected milk and food-supplies are not considered in this study of the statistics of large cities. Their effect cannot be great on the annual rate, and the sources of such epidemics are usually not difficult to locate. They are becoming now of great rarity. The statistics of Munich, Vienna, Zurich, Berlin, and Dresden, with their uniformly low typhoid death-rates, show how small the influence of such epidemics may be on the annual rate.

The supplies of nearly all the cities which we have studied are drawn from sources which we know may possibly be polluted by surface washings and percolation through the soil, due to rainfall. Of course supplies derived from mountain springs, certain deep ground-waters, and waters filtered before delivery to the consumers must be excepted from this generalization. It has been shown that the supplies of New York City and Boston, which have perhaps the most carefully protected watersheds of any large cities in this country, are not free from the influence of the rainfall, so far as typhoid-fever death-rates are concerned. In years of excessive rainfall typhoid fever has been prevalent, and in years of scanty rainfall it has been correspondingly infrequent. This might indicate that the regulations of the State boards of health were not sufficiently comprehensive to effect the efficient protection of the water, were it not that the cities

of Glasgow and Manchester, in Great Britain, having similar supplies, exhibit typhoid-fever death-rates of about the same amounts as those of New York and Boston. Manchester has purchased and owns the entire watershed of Lake Thirlmere, from which its main supply is drawn, and Glasgow has a most rigid, carefully devised system of pollution prevention. The most reasonable view that may be entertained of the protection of such supplies seems to be that there must be expected a certain amount of unpreventable pollution, dependent upon the annual rainfall. The source of pollution in these cases is to be sought for in the washing into the reservoirs of the wastes from the very scattered habitations and farms on their watersheds by the rains; and also we should recognize the importance of flies and other winged insects and birds which feed on offal as carriers of bacteria of specific diseases from points of infection to the watersheds, and the consequent washing of newly infected matter into our drinking-water by rains. The same considerations apply to all the other classes of water as found in nature, excepting to pure spring- and very deep ground-waters, and the statistics show that supplies derived from the great lakes, from large rivers, from upland streams and lakes, and from springs in populous valleys, are all susceptible to this unknown influence dependent upon the annual rainfall. As regards the pollution occasioned by the direct discharge of sewage into watercourses used as sources of supply, the statistics show very clearly that the greater the evident pollution the higher the death-rates from

typhoid fever, and that these facts are apparently true in all climates and countries from which we can get the necessary information. A further suggestion is offered by a study of the data presented: if it be granted that the typhoid-fever death-rate is so sensibly affected by the quality of the water, efficient filtration seems to be the means by which we must eventually combat and control the mortality from this disease and others which may be carried in water.

CHAPTER IV.

CONCLUSION.

A REVIEW of the matter which has been discussed in the foregoing pages suggests the following propositions:

1. In large cities having a pure water-supply and no sewers or drains the typhoid-fever death-rate is very sensitive to meteorological influences.

2. In large cities having a pure water-supply and efficient sewerage and drainage the typhoid-fever death-rate is not sensitive to meteorological conditions.

3. In large cities having sewerage and drainage, and water-supplies which are liable to pollution, the typhoid-fever death-rate is dependent mainly on the quality of the water supplied, and the quality is influenced sensibly in some localities by meteorological conditions.

4. The amount of bacterial self-purification that takes place in large sewage polluted rivers, as indicated by the typhoid-fever death-rates of cities using their waters, is insignificant. Rivers that have received relatively small amounts of pollution sometimes show so little improvement in quality, even after many

miles of flow, with the attendant dilution and dispersion, as to indicate great latent danger in their use.

5. The sedimentation and oxidation occurring during storage in large impounding reservoirs and lakes for periods of many days, and sometimes weeks, is not sufficient to completely remove the influence of meteorological conditions on the typhoid-fever death-rate, and this influence, although small in comparison with that arising from direct sewage contamination, is nevertheless positive and recognizable.

6. All supplies for large cities gathered upon the surfaces of the hills and valleys, and not subjected to long storage, are liable to sudden and variable degrees of pollution from washings from the surface, as well as from the direct discharge of sewage into the stream.

7. Supplies derived from the great lakes are in no case, so far as we know, exempt from danger; and the danger increases with the amount of shipping, and the proximity of the intake to the shore and to places where the pollution is greatest. In some cases the pollution is so positive that an increase in rainfall shows in the typhoid death-rate in the city, indicating that more polluting matter has been discharged into the lake by surface washings and carried out to the intake by currents, shipping, and other influences.

8. In some cases a decrease in typhoid fever has occurred with increase of rainfall in cities having efficient sewerage and drainage; which might indicate, in these cases, that the influence of dilution toward apparent purification was greater than that of surface washings toward pollution.

9. The typhoid-fever death-rate in large cities is dependent to a great degree upon the quality of the water which is supplied to its inhabitants.

10. In cities using polluted supplies no worse than the Elbe, Thames, Danube, Merrimac, etc., efficient filtration may be relied upon to reduce the typhoid-fever death-rates by such an amount that in 75 per cent of the cases the rate per 100,000 per annum will fall between 3 and 20.

APPENDIX A.

DEATH-RATES FROM TYPHOID FEVER, PER 100,000 OF POPULATION PER ANNUM, IN VARIOUS CITIES, FOR THE YEARS 1890–1895, INCLUSIVE.

Name of City.	1890.	1891.	1892.	1893.	1894.	1895.
Albany	60	108	50	59	52	165
Amsterdam	19	11	15	16	8.5	....
Atlanta	149	119	87	66	43	....
Baltimore	57	34	42	47	49	28
Berlin	9	10	8	9	4	....
Boston	43	33	25	26	23	32
Breslau	15	12	15	10	6.1	....
Brooklyn	21	21	18	18	15.6	16
Brussels	26	41	23	27	14	....
Buda-Pesth	34	23	26	15	14	....
Buffalo	44	56	38	37	62	28
Cambridge, Mass	34	....	20	21	29	15
Camden, N. J	141	56	63	60	67	69
Chicago	83	160	103	42	31	32
Cincinnati	67	62	40	43	50	36
Cleveland	66	52	54	47	27	36
Columbus, O	74	51	46	45	48	51
Copenhagen	9	8	7	9	6.7	....
Dayton	20	32	44	64	20	....
Detroit	18	13	51	61	26	24
Dresden	9	8	5	4.5	8.2	....
Denver	217	....	53	57	35	30
Edinburgh	19	18	13	14	15	....
Fall River	62	....	38	20	29	33
Frankfort on the Main	8	5	8	4	7	....
Genoa	....	....	23	35	13	....
Glasgow	26	31	18	20	24	....
Grand Rapids, Mich	50	65	74	94	45	28
The Hague	3	12	4	2	3.4	....
Hamburg	28	23	34	18	6	....

APPENDIX A.—(*Concluded*).

Name of City.	1890.	1891.	1892.	1893.	1894.	1895.
Hamilton, Ont	30	20	30	10	20	....
Hartford	60	73	82	50	51	58
Jersey City	97	102	73	68	56	73
Lawrence	123	115	95	69	48	31
Lincoln, Neb	37	24	53	58	26	38
Liverpool	24	25	25	53	58	....
London	16	15	11	16	15	....
Louisville	88	81	72	84	72	77
Lowell	82	96	90	62	60	39
Manchester	31	39	25	25	18	....
Milwaukee	33	33	31	37	26	25
Minneapolis	41	45	36	60	45	38
Montreal	....	....	....	20	20	23
Munich	8	7	3	15	2.5	....
Newark	107	72	79	31	21	21
New Haven	28	20	29	31	26	34
New Orleans	20	23	21	15	28	41
New York	21	22	14	20.5	17	17
Omaha	36	20	13	14	25	12
Paris	30	20	28	25	29	....
Paterson	29	21	18	40	37	21
Philadelphia	64	64	34	41	32	....
Pittsburg	131	100	100	111	56	77
Providence	29	47	36	34	49	31
Quebec	....	....	...	50*	22	18
Reading	54	48	45	38	47	51
Richmond	88	60	68	53	31	27
Rochester	33	36	52	39	12	24
Rome	35	36	26	34	30	....
Rotterdam	6	4	6	5	4.8	....
San Francisco	45	34	32	34	37	32
Scranton	57	54	93	62	82	105
St. Louis	34	30	37	103	31	19
Sydney, N. S. W	....	....	20	19	29	....
Syracuse	33	49	34	31	45	....
Toledo	42	26	37	28	26	35
Toronto	80	90	40	40	20	....
Trenton	19	25	22	28	23	16
Troy	42	80	44	57	54	51
Vienna	9	6	8	7	5	....
Venice	44	33	30	26	18	....
Warsaw	21	25	30	19	18	....
Washington	89	86	72	72	72	69
Wilmington	89	53	43	69	41	38
Worcester, Mass	17	21	57	33	32	25
Zurich	10	8	9	8	7	....

* 25 for half-year.

APPENDIX B.

DESCRIPTIONS OF THE SOURCES OF THE WATER-SUPPLIES OF VARIOUS CITIES.

ALBANY,* N. Y.; Population 98,000.† Supply: Patroon and Sand creeks by gravity, and Hudson River by pumping to high-service reservoir. In 1891, Rudolph Hering and Jno. Bogart, Mems. Am. Soc. C. E., recommended a new supply from Norman's Kill with storage reservoirs of capacity of 1,955,000,000 gals. Recently filtration has been reported on by Allen Hazen, Assoc. M. Am. Soc. C. E.

AMSTERDAM, HOLLAND; 438,000. Filtered water from the Haarlem dunes.

ATLANTA, GA.; 65,500. Supply: South River, pumping to a reservoir. Sept. 21, 1893, new supply from Chattahoochee River with mechanical filters was introduced, and the South River plant was abandoned. Some wells are still in use in the central part and suburbs of the city.

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* Pollution of Hudson River, Rep't N. Y. State Board of Health, 1891 *et seq.*; also Report of Allen Hazen on Filtration of Albany Water-supply.

† The populations given are for 1895 unless otherwise mentioned.

BALTIMORE, MD.; 435,000. Impounding reservoirs on Gunpowder River, forming Loch Raven, capacity 570,000,000 gals., and Lake Montebello, capacity 496,378,000 gals. Also an additional supply from Jones's Falls by a dam forming Lake Roland, capacity 400,000,000 gals., and Druid Lake, in Druid Hill Park, with a capacity of 463,000,000 gals.

BERLIN, GERMANY; 1,750,000. Filtered waters of the rivers Spree and Havel. Suburbs supplied with filtered ground-waters.

BOSTON, MASS.; 450,000. Lakes and impounding reservoirs.

BRESLAU, GERMANY; 353,000. Filtered water of the river Oder.

BROOKLYN, N. Y.; 1,012,000. Surface-water impounded in reservoirs; also Andrews's system of driven wells.

BRUSSELS, BELGIUM; 500,000. Principally collecting mains and wells 100 feet below the surface to gather ground-water under a forest used as a city park.

BUDA-PESTH, HUNGARY; 500,000. Filtered water of the Danube and ground-water. In 1894 the filters were only used as a supplementary supply to the ground-water, and it was hoped that they would soon be able to abandon the filters.

BUFFALO, N. Y.; 300,000. Supply from Lake Erie.

CAMBRIDGE, MASS.; 80,000. Storage reservoirs on Stony Brook in Waltham and Weston, capacity 354,000,000 gals., and Fresh Pond, area 165 acres,

maximum depth 46 feet. Considerable population on the watersheds of both. Water from Stony Brook reservoirs is aerated through a nozzle at Fresh Pond.

CAMDEN, N. J.; 58,000. Delaware River, pumped to a service reservoir and standpipe.

CHICAGO, ILL.; 1,600,000 (1890). Lake Michigan, pumped through various intakes and tunnels extending under the lake. The four-mile intake was opened in 1893. During 1896 another severe outbreak of typhoid occurred in Chicago.

CINCINNATI, OHIO; 300,000. Ohio River, pumped to a reservoir. Intake opposite centre of city, about 5 miles below the upper limits.

CLEVELAND, OHIO; 325,000. Lake Erie. The last tunnel was opened Jan. 22, 1891. A new system of intercepting sewers and another tunnel were reported on in February 1896 by Rudolph Hering, Geo. H. Benzenberg, and Desmond Fitzgerald, Mems. Am. Soc. C E.

COLUMBUS, OHIO; 130,000. Filter-gallery along Olentangy River, passing under the same to the Scioto River, where an inlet is provided for emergencies.

COPENHAGEN, DENMARK; 350,000. Driven and other wells over a large extent of territory, mostly to the northwest of the city.

DAYTON, OHIO; 65,000. Tube-wells, driven in 1870.

DETROIT, MICHIGAN; 206,000. Detroit River, practically the waters of Lake Huron or Lake St. Clair.

DRESDEN, SAXONY; 280,000. Pipes and wells along the bank of the Elbe to collect the ground-water from under the Stadtwald.

EDINBURGH, SCOTLAND; 261,000. Filtered surface-water from the Pentland and Moorfoot Hills. They are now (1896) constructing a storage supply on the headwaters of the Tweed.

FALL RIVER, MASS.; 85,000. Watuppa Lake, area 3478 acres, maximum depth 30 feet. Very small population on watershed.

FRANKFORT ON THE MAIN; 183,000. Spring-water and ground-water collected on the Sachsenhausen side of the Main, under a primeval forest owned by the city. The water for street-sprinkling comes from the Main, but is not used for potable purposes.

GENOA, ITALY; 212,000. Three aqueducts, bringing the waters of small streams from populated valleys in the mountains.

GLASGOW, SCOTLAND; 810,000. Waters of Loch Katrine and impounding reservoirs.

GRAND RAPIDS, MICH.; 60,300. Receiving-wells supplied by springs; also Grand River, with collecting-galleries in bed of river, and a supply from the river direct.

THE HAGUE, HOLLAND; 170,000. Filtered water collected from drains in the sand-dunes.

HAMBURG, GERMANY; 640,000. Until May, 1893, the raw water of the Elbe; since that date, filtered Elbe water.

HAMILTON, ONT.; 50,000. Lake Ontario.

HARTFORD, CONN.; 60,000. Brooks by gravity from storage reservoirs. New reservoir completed in 1895. There is also an emergency supply from the Connecticut River, from which they were obliged to draw in 1892, and again in the winter of 1893; in 1894 they managed to avoid it.

JERSEY CITY, N. J.; 182,700. Passaic River, pumped to a reservoir.

LAWRENCE, MASS.; 50,500. Source: Merrimac River, introduced in 1875. Water is taken direct from the river, and also from a filter-gallery near the river. Only a small part, however, comes from the latter. Filters introduced in September, 1893; a portion of the people, however, may still use the unfiltered river-water, particularly in factories.

LINCOLN, NEB.; 55,000. Well in Lincoln Park and 100 driven wells.

LIVERPOOL, ENG.; 800,000. Vyrnwy River, impounded to form lake 84 feet deep. Water is filtered at Oswestry to remove the color. Also wells and filters at Rivington, near Manchester.

LONDON; 5,000,000. Filtered Thames and Lea water, and wells in the chalk formation in Kent.

LOUISVILLE, KY.; 162,000. Ohio River, pumped to reservoir and standpipe; also private and public wells (121 tube-wells and 532 open wells).

LOWELL, MASS.; 83,000. Source: Merrimac River above city, from a dam of the "Locks and Canals Co." It is taken directly from the river, also from a filter-gallery 1300′ × 8′ × 8′, and a small

filter of 11,400 sq. ft. Ordinarily the filter-gallery and bed supply but a very small portion of the water used by the city. Population above Lowell on the river in 1880 was about 230,266. On March 7, 1893, the first Cook Well was driven, and the system has since been extended and the river water gradually disused. On Feb. 22, 1895, the river-gate was closed, and nothing but well-water has been used since.

MANCHESTER, ENG.; 600,000. Waters of Lake Thirlmere, brought 95 miles, and Longdendale impounding reservoirs, 18 miles east of Manchester. The city has purchased the entire watershed of Lake Thirlmere to protect its purity.

MILWAUKEE, WIS.; 204,500. Lake Michigan through a tunnel.

MINNEAPOLIS, MINN.; 165,000. Mississippi River. In 1894, F. W. Cappelen, C.E., recommended mechanical filters.

MONTREAL, CANADA; 253,400. St. Lawrence River, pumped to a reservoir.

MUNICH, BAVARIA; 350,000. Springs from the Mangfall Thal, 30 miles from Munich, derived from the foothills of the Alps by percolation from the Tegern See through the gravel deposits.

NEWARK, N. J.; 210,000. Passaic River, pumped to reservoir. April 12, 1892, the waters of the Pequannock were brought in. Area of Pequannock watershed about 63 sq. miles; storage capacity of reservoirs about 6,000,000,000 gals.

NEW HAVEN, CONN.; 100,000. Mill River, dammed

2 miles from city, in a narrow gorge, forming a storage reservoir 25 miles long; average depth 20 feet. Also Lakes Maltby, Wintergreen, and Saltonstall. Drainage area of river, 56 sq. miles; of lakes, over 5 sq. miles.

NEW ORLEANS, LA.; 243,000. Mississippi River. A mechanical filtration plant was in use for a time about 1893, but it was not successful on account of the great quantities of suspended matter in the water.

NEW YORK, N. Y.; 1,900,000. Large impounding reservoirs.

OMAHA, NEB.; 140,000. Missouri River, 6 miles above the city, at Florence, pumped into large settling-basins and thence to city.

PARIS; 2,500,000. The greater part of the supply for the heart of Paris comes from large springs of the Vanne and the Dhuis, and also from some artesian wells; but some of the suburbs use unfiltered river-water (Seine). They are now experimenting with filters.

PATERSON, N. J.; 100,000. Passaic River, pumped to reservoir.

PHILADELPHIA, PA.; 1,150,000. Schuylkill and Delaware rivers and springs. Main supply from the Schuylkill River.

PITTSBURG, PA.; 240,000. Allegheny and Monongahela rivers, pumped to a reservoir; also a number of springs and wells, in suburban districts, which are not above suspicion.

PROVIDENCE, R. I.; 146,000. Pawtuxet River,

pumped to reservoirs; capacity 125,000,000 gals.; intake, 6 miles above city.

QUEBEC, CANADA; 63,400. St. Charles River, by gravity.

READING, PA.; 71,000. Springs and creeks by gravity, pumped to reservoir, and direct; with reserve from Maiden Creek by pumping. Some of the tributary streams are subject to direct pollution from privies, pig-pens, and barnyards.

RICHMOND, VA.; 96,600. James River, pumped to high- and low-service reservoirs. Chas. E. Bolling, the superintendent, has recommended storage and settling basins.

ROCHESTER, N. Y.; 150,000. Supply from Hemlock Lake for domestic purposes, and from the Genesee River for manufacturing. Hemlock Lake is 6.6 miles long and 0.6 mile wide; watershed is hilly, 29 miles south of Rochester; area of lake 1828 acres; average depth in middle is 65 feet. Watershed 43.05 sq. miles, a large part of which is steep and covered with forests. Total population on watershed probably about 1600.

ROME, ITALY; 445,000. Mostly springs in populous valleys and water of Lake Bracciano, brought in by four aqueducts.

ROTTERDAM, HOLLAND; 224,000. Filtered water of the river Maas.

SAN FRANCISCO, CAL.; 330,000. Mountain streams and Lake Merced. A large aerating plant has been recently installed. The water falls over a series of perforated platforms to a reservoir,

SCRANTON, PA.; 75,200. Source: mostly Roaring Brook, supplemented by impounding reservoir, finished at end of 1889, on Oak Run, a small tributary.

ST. LOUIS, MO.; 452,000. Mississippi River. In September, 1894, the intake at Bissell's Point was closed and the works at Chain of Rocks, with settling-basins, were put in operation.

SYDNEY, N.S.W.; 300,000. Impounded waters from the Upper Nepean.

SYRACUSE, N. Y.; 92,000. Old sources: Springs on State lands east of Syracuse and gang wells to the southwest of city, pumped to a reservoir, supplemented by a supply from Onondaga Creek. These supplies were all considered with suspicion by J. Jas. R. Croes, C. E., M. Am. Soc. C. E., when making studies for a new supply in 1888–1890. The new supply was recommended to be taken from Skaneateles Lake; construction was begun Jan. 1, 1891, under W. R. Hill, Chief Engineer. The new water-works were opened July 3, 1894. There are, however, a good many private wells in use in the city also.

TOLEDO, OHIO; 122,400. Maumee River. Intake consists of narrow, long, hexagonal crib, placed longitudinally with current of river, formed of a double row of piles driven close together around the periphery. The space between the rows is filled with broken stone, and inside with gravel; also a small filter of 19,000 sq. ft., which has proved so small as to be useless.

TORONTO, CANADA; 225,000. Lake Ontario. They have had a good many leaks into the intake-pipe by floating of the suction-pipe and other causes.

TRENTON, N. J.; 71,000. Delaware River, pumped to a reservoir.

TROY, N. Y.; 65,000. Hudson River opposite Waterford, and from a creek east of the city.

VIENNA, AUSTRIA; 1,370,000. Springs in the Austrian Alps; the "Kaiserbrunnen," and "Stixtensteiner Quelle," 60 miles from Vienna.

VENICE, ITALY; 160,000. Rain-water stored in cisterns until 1890. In that year a ground-water supply was developed near Castel Franco, 25 miles from Venice.

WARSAW, POLAND; 500,000. Filtered water of the Weichsel River. In 1895 only about 50 per cent of the houses were connected with the water-mains.

WASHINGTON, D. C.; 230,000. Potomac River and a great number of public and private wells and pumps.

WILMINGTON, DEL.; 72,500. Brandywine Creek, pumped to reservoirs. There are also an aerating plant and a very small sand-filter, put in operation in the latter part of 1893.

WORCESTER, MASS.; 96,000. Sources: Lynde Brook and Tatnuck Brook. In each a storage reservoir is built. Lynde Brook reservoir has a capacity of 681,000,000 gals.; Tatnuck Brook reservoir holds 450,000,000 gals. Small agricultural population on watersheds of each.

ZURICH, SWITZERLAND; 105,000. Filtered water of the Lake of Zurich.

APPENDIX C.

ANNUAL PRECIPITATION OF RAINFALL IN VARIOUS CITIES FOR 1890-1895, INCLUSIVE.

Furnished by WILLIS L. MOORE, Chief of U. S. Weather Bureau.

Stations.	1890.	1891.	1892.	1893.	1894.	1895.
Albany	44.89	41.68	34.83	35.39	35.11	29.80
Atlanta	42.60	49.97	49.87	36.43	40.92	45.92
Baltimore	46.96	54.21	45.05	32.15	38.32	40.47
Boston	45.93	39.70	37.02	41.84	36.62	40.17
*Brooklyn	No	recor	ds.			
Buffalo	46.55	31.74	45.87	38.64	38.92	33.02
Cambridge	43.80	42.50	36.41	41.00	32.46	43.55
Camden, N. J.	See	Phila	delph	ia, Pa.		
Chicago	32.69	26.54	36.56	27.47	27.46	32.38
Cincinnati	47.70	38.44	31.95	44.00	26.59	29.33
Cleveland	47.82	34.18	36.51	33.88	27.73	26.84
Columbus	50.73	42.05	33.54	38.16	29.49	30.74
Dayton	42.60	39.00	31.40	38.90	27.60	25.89
Detroit	34.99	28.83	37.11	34.18	25.74	25.04
Denver	9.33	21.43	15.02	8.48	15.09	16.12
Fall River	58.50	49.90	44.66	55.38	46.10	42.31
Grand Rapids, Mich.	26.50	*—	*—	*—	26.18	31.11
Hartford	50.60	*—	39.10	49.00	43.05	48.35
*Jersey City	No	recor	ds.			
Lawrence, Mass.	50.50	40.10	34.90	41.96	31.35	38.05
Lincoln, Neb.	14.41	40 08	29.91	19.74	18.93	*—
Louisville, Ky.	55.41	43.42	38.13	43.93	38.08	38.86
Lowell, Mass.	51.20	42.50	39.22	44.74	34.40	40.73
Milwaukee, Miss.	30.29	29.76	35.03	32.87	27.79	24.88
Minneapolis, Minn.	27.07	25.26	36.72	29.93	22.84	21.44
Newark, N. J.	50.80	46.30	42.52	52.06	*—	40.03
New Haven, Conn.	48.95	44.69	37.78	46.71	37.74	35.96
New Orleans, La.	42.17	38.62	56.91	48.02	54.44	56.44
New York, N. Y.	52.21	41.44	38.90	53.01	44.17	35.73

* No records at Washington.

APPENDIX C.—(*Concluded.*)

Stations.	1890.	1891.	1892.	1893.	1894.	1895.
Omaha	22.08	34.92	29.44	26.66	17.82	21.69
Paterson, N. J	*——	*——	44.09	54.19	45.29	41.42
Philadelphia, Pa	34.02	38.19	34.78	37.65	40.34	31.01
Pittsburg, Pa	50.61	38.28	32.66	37.84	28.17	27.50
Providence, R. I	49.62	55.98	36.78	52.56	42.97	52.22
Reading, Pa	*——	48.97	36.35	38.68	51.77	33.34
Richmond, Va	43.50	52.80	37.63	46.04	46.14	41.17
Rochester, N. Y	43.09	33.64	35.02	35.50	35.11	30.42
San Francisco, Cal	25.43	21.11	22.08	17.91	24.32	17.13
*Scranton, Pa	No	recor	ds.			
St. Louis, Mo	37.63	30.53	41.62	39.33	27.44	31.20
*Syracuse	No	recor	ds.			
Toledo, Ohio	33.64	27.12	36.70	23.81	21.34	25.31
Trenton, N. J	51.00	48.80	45.53	46.33	48.52	37.34
*Troy	No	recor	ds.			
Washington, D. C	41.59	52.95	42.34	36.71	30.85	34.25
Wilmington, Del	*——	*——	*——	*——	*——	34.67
Worcester, Mass	57.70	*——	*——	44.78	29.73	48.52

* No records at Washington.

APPENDIX D.

TABLE SHOWING THE NUMBER OF TIMES THAT DIFFERENT TYPHOID - FEVER DEATH - RATES PER 100,000 OCCURRED IN ALL THE CITIES CONTAINED IN APPENDIX A. DURING THE SIX YEARS 1890–1895.

NUMBER OF TIMES A GIVEN DEATH-RATE PER 100,000 IS RECORDED IN THE SIX YEARS 1890–1895, INCL.

Typhoid-fever Death-rate per 100,000 per Annum.	Filtered Waters.	Ground-waters.	Impounded Waters.	Normal River-waters.	Great Lakes.	Upland Streams.	Polluted Waters.
2	1						
3	2						
4	3	1					
5	2	3					
6	4						
7	< . . . 29 times between 7 and 18. . . . >	4					
8		4					
9		< . . . . 15 times between 9 and 26					
10					1		
11							
12			1	1	1		
13				1			
14			1	1		1	
15			1				
16			3	2			
17			2				
18			4	2	1		
19	3		2	3			
20			6	3	3		

APPENDIX D.—(*Continued.*)

Typhoid-fever Death-rate per 100,000 per Annum.	Filtered Waters.	Ground-waters.	Impounded Waters.	Normal River-waters.	Great Lakes.	Upland Streams.	Polluted Waters.
21	1	<..........	<.... 33 times between 21 and 32. ...>	<...20 times between 21 and 35...>			
22							1
23	1					1	
24					1		
25	1				<........ 20 times between 25 and 45 ....>		
26	1						
27							
28		2				2	3
29							
30	1	2				3	
31						1	
32		1				2	2
33		1	2			<......... 31 times between 33 and 54 ....>	
34	1		4				
35							2
36			1	2			
37		1		3			1
38	1	1		1			
39	4	1	3				
40				1			1
41		1		2			1
42			1	1			2
43			1				1
44		2	over 44				1
45				2			<..69 times between 45 and 96......>
46			8				
47					1		
48	1						
49							
50		over 50					
51		3			1		
52					1		
53							
54					1		
55					1		
56							
57						2	
58						1	
59							

APPENDIX D.—(*Concluded.*)

Typhoid-fever Death-rate per 100,000 per Annum.	Filtered Waters.	Ground-waters.	Impounded Waters.	Normal River-waters.	Great Lakes.	Upland Streams.	Polluted Waters.
60				1		1	. . . 69 times between 45 and 96
61							
62					3	1	
63							
64						1	
65						1	
75						1	
80					1		
84					1		
85						2	
90					1	over 90	
91						3	
96							
100					over 100		3
101					2		
102							1
103							
104							1
105							
106							1
107							over 107
108							15
Totals..	53	42	73	45	40	54	105

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